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Uranium and Thorium Occurrences in New Mexico: Distribution, Geology, Production, and Resources, with Selected Bibliography

by

Virginia T. McLemore

New Mexico Bureau of Mines and Mineral Resources

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Abstract

Uranium and thorium in New Mexico are found in rocks of all ages and lithologies, from Precambrian granites to recent travertine deposits. They occur in sandstones, coals, limestones, shales, igneous and metamorphic rocks, pegmatites, veins, volcanic rocks, and breccia pipes. Over 1,300 uranium and thorium occurrences are found in over 100 formational units in all but two counties, in all 1- by 2-degree topographic quadrangles, and in all four geographic provences in New Mexico.

Uranium production in New Mexico has surpassed yearly production from all other states since 1956. Over 200 mines in 18 counties in New Mexico have produced 163,010 tons (147,880 metric tons) of U_3O_8 from 1948 to 1982, 40% of the total uranium production in the United States. More than 99% of this production has come from sedimentary rocks in the San Juan Basin area in northwestern New Mexico; 96% has come from the Morrison Formation alone.

All of the uranium reserves and the majority of the potential uranium resources in New Mexico are in the Grants uranium district. About 112,500 tons (102,058 metric tons) of $30 per pound of U_3O_8 reserves are in the San Juan Basin, about 55% of the total $30 reserves in the United States. Thorium reserves and resources in New Mexico have not been adequately evaluated and are unknown.

Over 1,300 uranium and thorium occurrences are described in this report, about 400 of these have been examined in the field by the author. The occurrence descriptions include information

on location, commodities, production, development, geology, and classification. Over 1,000 citations are included in the bibliography and referenced in the occurrence descriptions. Production statistics for uranium mines that operated from 1948 to 1970 are also included. Mines that operated after 1970 are classified into production categories.

This compilation and study of uranium and thorium occurrences is required in establishing a data base which can be used by health and safety personnel, government agencies in planning impact studies, uranium geologists, mineralogists, and the general public. The genesis and origin of uranium mineralization in the Grants uranium district in New Mexico may be better understood with such a data base.

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Introduction

Purpose and Scope

Uranium production in New Mexico has surpassed production from all other states in the U.S. since 1956. Over 200 mines in 18 counties in New Mexico have produced 163,010 tons (147,880 metric tons) of U_3O_8 from 1948 to 1982, 40% of the total uranium production in the U.S. However, much of the information concerning individual mine production statistics, geology, history of development, and occasionally actual location is widely scattered in published reports and state and federal government unpublished documents, many of which had been previously classified or otherwise unavailable to the general public. Many uranium and thorium occurrences are described only in these obscure reports.

The primary objectives of this report are (1) to present a summary of this information, (2) to compile all known uranium and thorium occurrences in New Mexico, and (3) to compile a selected bibliography of reports pertaining to uranium and thorium geology in New Mexico. The first part of this report summarizes the geology, types, and distribution of uranium and thorium in New Mexico according to classification of deposits. Production statistics for individual mines operating from 1948 to 1970 are tabulated in Appendix 3 (Table 3-1). Production statistics for individual mines operating after 1970 are confidential; these mines are grouped into production classes, and are also listed in Appendix 3 (Table 3-2). Production, reserves, and potential are briefly discussed in the first portion of this report.

A descriptive compilation of all known uranium and thorium occurrences, prospects, deposits, and mines in New Mexico is in Appendix 1 of this report. This compilation is the most comprehensive tabulation of naturally occurring uranium and thorium occurrences in New Mexico to date. For the purposes of this report, an occurrence is defined as (1) any locality where uranium or thorium mineralization is reported to occur or produced; (2) where uranium or thorium concentration exceeds 0.001%; or (3) where radioactivity is twice the background radioactivity. Any locality that has been developed, but not produced is considered a prospect. A deposit is any delineated ore body of economic or subeconomic size. A mine is any locality that has produced uranium or thorium. The occurrences are arranged in alphabetical order by county and indexed according to aliases, numerical order, mining districts, and 1- by 2-degree topographic quadrangles. In addition each occurrence or group of occurrences is plotted on a state map (Fig. 1) and county maps (Appendix 1; Figs. 1-5 to 1-33). The major emphasis is on geology, production, extent of development, and geographic location; less emphasis is placed on genesis of mineralization. Chemical analyses of samples collected during field reconnaissance are listed collectively in Appendix 2.

A selected bibliography of over 1,000 citations of reports pertaining to uranium and thorium geology that have been published since 1972 or have been declassified and released since 1972 comprises Appendix 4. Most pre-1972 publications pertaining to uranium geology of the Grants uranium district are included in an annotated bibliography by F. A. Schilling, Jr. (1975). The bibliography in this report is an attempt to add reports not cited in Schilling's (1975) annotated bibliography, although many reports are cited in both bibliographies. Maps, articles, and other reports not specifically pertaining to uranium geology may be included in this bibliography because they describe the general geology of an occurrence or group of occurrences in Appendix 1. All references cited in the text and appendices of this report are cited in the Bibliography in Appendix 4.

A compilation and study of uranium and thorium occurrences is required for establishing a data base which can be used by health and safety personnel, government agencies in planning impact studies, uranium geologists, mineralogists, and the general public. The genesis of uranium mineralization in the Grants uranium district in New Mexico can be addressed and perhaps better understood with such a data base. Exploration of new ore bodies can be achieved only with such a data base. This report has provided such a source of information.

Previous Work

Previous compilations of uranium and thorium occurrences in New Mexico are limited and generally incomplete. The earliest compilations consist of geologic reports of radium occurrences originally found in the early 1920's; some of these reports are by Fischer (1937, 1943), A. H. Coleman (1944), Harder and Wyant (1944), Harder and Stead (1945), Keith (1944, 1945a, b), and Stokes (1951). Later compilations by Hilpert and Corey (1955), E. C. Anderson (1955, 1957), and Chew (1956) list and locate major uranium occurrences and mines known by the mid-1950's. The first descriptive and fairly complete compilations of uranium occurrences in northwestern New Mexico were by Hilpert and Corey (1955) and Hilpert (1965, 1969); in these reports over 500 uranium occurrences were described. About 200 abandoned uranium mines and prospects in New Mexico were examined by O. J. Anderson (1980) of the New Mexico Bureau of Mines and Mineral Resources for the New Mexico Abandoned Mine Lands (AML) program. This project was the first compilation of abandoned uranium mines in the entire state.

Many regional studies of uranium and thorium occurrences were reported by numerous authors, including Chenoweth (1957a, 1957b, 1973a, 1974a, 1974b, 1976, 1977, 1979, 1980), Bachman and others (1953), Griggs (1953), Waltman (1954), Boyd (1955), Boyd and Wolfe (1953), Moench and Schlee (1967), Tschanz and others (1954, 1958), Finch (1972), McLemore (1982a, 1982c, 1983b, 1983c), and McLemore and Menzie (1983). Additional studies by the geologists with the U.S. Atomic Energy Commission (AEC) and the U.S. Geological Survey (USGS) were completed during the 1950's and 1960's and released as TM (Technical Memorandum), RME (Raw Materials Exploration), RMO (Raw Materials Operations), TEI (Trace Elements Investigations), TEM (Trace Elements Memorandum) reports, and other miscellaneous report series. Many of these reports have only recently been made available to the general public; these reports are cited in the Bibliography by author (Appendix 4).

Thorium occurrences in New Mexico have received minor attention in the published literature. Staatz (1965, 1974) and Staatz and others (1979) briefly describe thorium occurrences in New Mexico. The thorium-bearing beach-placer sandstone deposits in the stape are described by Chenoweth (1957a), Dow and Batty (1961), Overstreet (1967), and Houston and Murphy (1977).

As part of the NURE (National Uranium Resources Evaluation) program, uranium and thorium occurrences were compiled for 13 1- by 2-degree topographic quadrangles in the state (Table 1). The New Mexico Bureau of Mines and Minral Resources evaluated two of these quadrangles, Raton and Santa Fe (Reid and others, 1980a, 1980b). Some of the HSSR (Hydrogeochemical and Stream-Sediment Reconnaissance) and ARMS (Aerial-Radiometric and Magnetic Survey) reports also list uranium occurrences (Table 1). Various additional U.S. Department of Energy (DOE) reports listing uranium and thorium occurrences are cited in the Bibliography.

Table 1 - Available 1- by 2-degree quadrangle NURE reports

1- by 2-degree quadrangle	HSSR reports	ARMS reports	NURE reports	Geologic Map 1:125,000 scale
Albuquerque	Olsen, C. E. (1977), Maassen and Bolivar (1979), Purson and others, (1981), Texas Instruments, Inc. (1982)	Geometrics (1979a)	Green and others (1980c)	USGS open-file report
Aztec	Bolivar (1978), Union Carbide Corp. (1981e)	Geodata International, Inc. (1980a) U.S. Department of Energy (1982)	Green and others (1980a)	USDOE[1]
Brownfield	Nichols and others (1976), Union Carbide Corp. (1981c)	Geodata International, Inc. (1976c)	——	Texas Atlas Map[2]
Carlsbad	Union Carbide Corp. (1981k)	Carson Helicopters, Inc. (1981e)	——	USDOE[1]
Clifton	Sharp and others (1978), Union Carbide Corp. (1981h)	Texas Instruments, Inc. (1978), U.S. Department of Energy (1982)	White and Foster (1981)	USDOE[1]
Clovis	Zinkl and others (1982)	Geodata International, Inc. (1976b)	——	USDOE[1], Texas Atlas Map[2]
Dalhart	Morgan (1980)	Texas Instruments, Inc. (1980), U.S. Department of Energy (1982)	Consulting Professionals, Inc. (1980)	USDOE[1], Texas Atlas Map[2]
Douglas	Sharp and others (1978), Union Carbide Corp. (1981a)	Texas Instruments, Inc. (1978)	May and others (1981)	USDOE[1]
El Paso	——	Carson Helicopters, Inc. (1981b)	——	USDOE[1]
Ft. Sumner	Olsen, C. E. (1977), Union Carbide Corp. (1981j)	Carson Helicopters, Inc. (1981d)	——	USDOE[1], Texas Atlas Map[2], Kelley, V. C. (197
Gallup	Maassen and others (1980), Purson and others (1981)	Geometrics (1979a), U.S. Department of Energy (1982)	Green and others (1980b)	Hackman and Olson (1977)
Hobbs	Warren and Nunes (1978), Union Carbide Corp. (1981b)	Geodata International, Inc. (1980b)	——	Texas Atlas Map[2]
Las Cruces	LaDelfe (1981), Union Carbide Corp. (1981L)	Carson Helicopters, Inc. (1981c)	——	USDOE[1], Seager (1982)
Raton	Morgan and Broxton (1978), Union Carbide Corp. (1981g)	Geometrics, Inc. (1979a), U.S. Department of Energy (1982)	Reid and others (1980b)	USDOE[1]
Roswell	Union Carbide Corp. (1981i)	Carson Helicopters, Inc. (1981d)	——	USDOE[1]
Saint Johns	Sharp and others (1978), Maassen and others (1980), Morgan (1981)	Texas Instruments, Inc. (1979a)	May and others (1980)	USDOE[1]
Santa Fe	Olsen, C. E. (1977), Bolivar (1980)	Geometrics (1979b), U.S. Department of Energy (1982)	Reid and others (1980a)	USDOE[1]
Shiprock	Morgan and others (1980)	Geometrics (1979a), U.S. Department of Energy (1982)	Green and others (1980d)	O'Sullivan and Beikman (196
Silver City	Sharp and others (1978), Union Carbide Corp. (1981d)	Texas Instruments, Inc. (1978), U.S. Department of Energy (1982)	O'Neill and Thiede (1981)	USDOE[1]
Socorro	Olsen, C. E. (1977), Planner (1980), Morgan and others (1981)	Geodata International, Inc. (1979b), U.S. Department of Energy (1982)	Pierson and others (1981)	Machette (1978)
Tucumcari	Langfeldt and others (1981)	Geodata International, Inc. (1976a)	——	USDOE[1], Texas Atlas Map[2]
Tularosa	Broxton (1978), LaDelfe (1981), Union Carbide Corp. (1981f)	Geodata International, Inc. (1979a) U.S. Department of Energy (1982)	Berry and others (1980)	USDOE[1]

1 - Geologic map by USDOE (U.S. Department of Energy) is blackline print and available at New Mexico Bureau of Mines and Mineral Resources; also included in most ARMS reports

2 - Geologic Atlas Map of Texas series from Texas Bureau of Economic Geology

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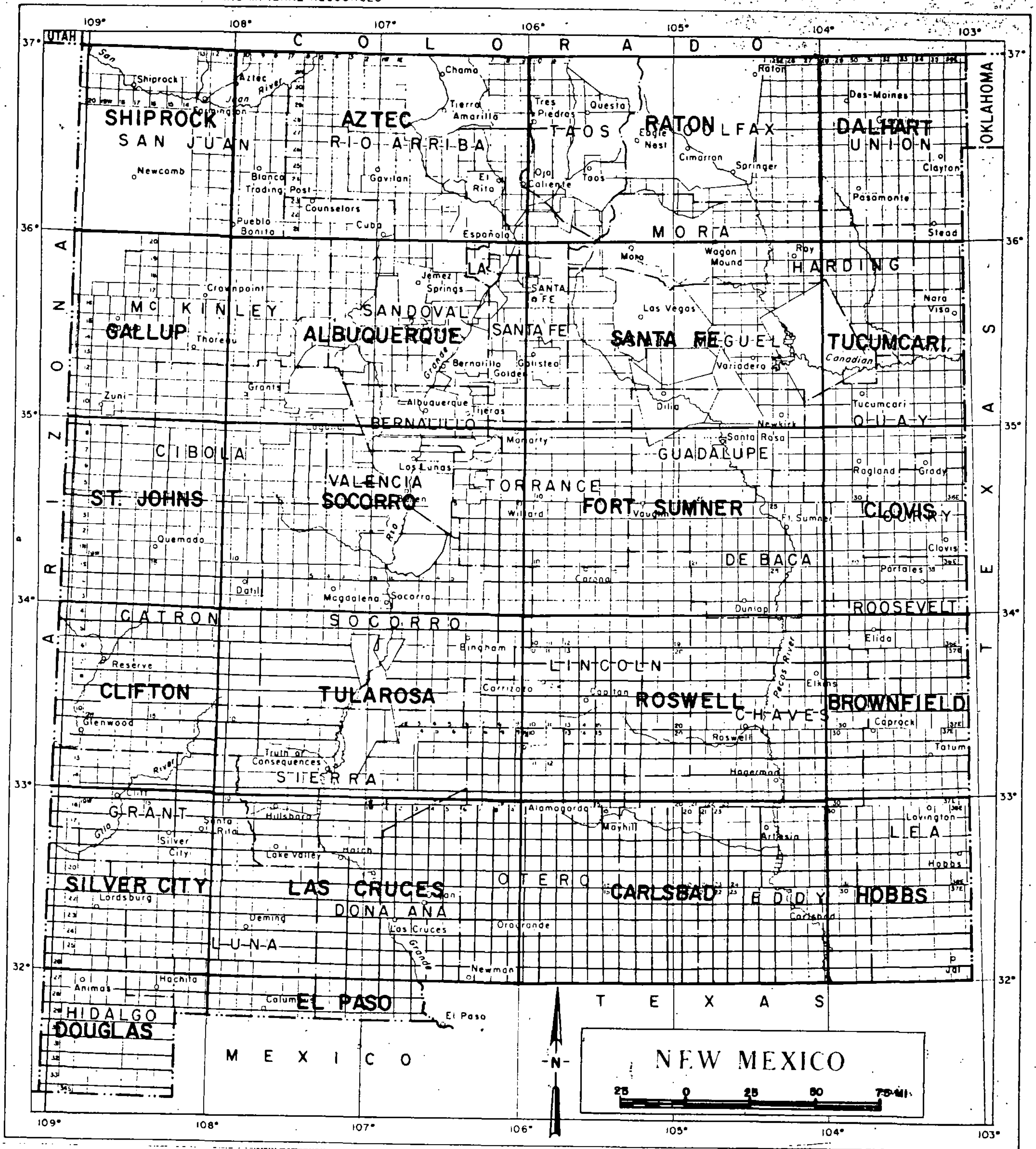

FIGURE 2- 1-BY 2-DEGREE TOPOGRAPHIC

QUADRANGLES IN NEW MEXICO

Methods of Investigation and Sources of Information

Information presented in this report was obtained from a large number of sources, including (1) published and unpublished reports cited in appendix 4, (2) AEC Preliminary Reconnaissance Reports, (3) AEC uranium production records for New Mexico for the years 1948 to 1970, (4) CRIB (Computerized Resource Information Bank-USGS), (5) MILS (Mineral Industry Location Survey-U.S. Bureau of Mines), (6) DMEA (Defense Minerals Exploration Administration) reports of the U.S. Bureau of Mines (USBM), (7) U.S. Bureau of Land Management (BLM) reports, (8) New Mexico Abandoned Mine Lands (AML) files, (9) miscellaneous state and federal government files, and (10) field reconnaissance.

Much of the information on uranium and thorium occurrences in New Mexico was obtained through an extensive literature search. Most of these reports are cited in the descriptions of occurrences (Appendix 1); the complete citations are in Appendix 4. The citations were compiled from a large number of sources including bibliographies and mapping indexes listed in Appendix 6. "Publications available from New Mexico Bureau of Mines and Mineral Resources", "Publications of the U.S. Geological Survey", "Publications of the U.S. Bureau of Mines", DOE News Releases, and DOE lists of reports were invaluable aids in obtaining citations of reports issued by these organizations. Card catalog files at the libraries at New Mexico Institute of Mining and Technology (Socorro) and University of New Mexico (Albuquerque) enabled the author to obtain published and unpublished reports and M.S. and Ph.D. theses and dissertations. The citations of these reports are included in the Bibliography (Appendix 4).

A major source of information on uranium and thorium occurrences in New Mexico is the Preliminary Reconnaissance Reports (PRR's) of the AEC and USGS. These reports are one- to three-page reports of field investigations of reported uranium occurrences completed in the 1950's, and were originally intended for government use only. However, in 1966 the AEC open-filed all known PRR's as PB-172678 through PB-172702 (arranged by county-U.S. Atomic Energy Commission, 1966b-1966z). Additional PRR's for New Mexico were found in AEC field office files, and in 1970 these reports were released as RME-160 (U.S. Atomic Energy Commission, 1970). In October 1980 and June 1982, additional PRR's in the Grand Junction (Colorado) and Albuquerque (New Mexico--now closed) offices of DOE were located that had not been previously open-filed. Copies of all known PRR's are on file at New Mexico Bureau of Mines and Mineral Resources (Socorro). These PRR's are tabulated in Appendix 5. The PRR's are cited in the occurrence descriptions (Appendix 1) by report number prefixed with PRR (i.e. PRR DEB-465) followed by the year in parenthesis, or as U.S. Atomic Energy Commission (1970). Most of the uranium produced from 1948 to 1970 was sold to the federal government; these production records are now public information.

The CRIB (Computerized Resource Information Bank) and MILS (Mineral Industry Location Survey) were used as additional sources of information. CRIB provides a summary of geology, production, exploration, and reserves on major mines, including uranium mines, in New Mexico. MILS provides location and commodity information on most prospects and mines in the state. The New Mexico Bureau of Mines and Mineral Resources, under the supervision of Robert Eveleth, was involved with both of these programs; this information is on file at the New Mexico Bureau of Mines and Mineral Resources (Socorro).

As part of the CRIB and MILS program, the New Mexico Bureau of Mines and Mineral Resources was able to obtain copies of some USBM DMEA (Defense Minerals Exploration Administration) reports. DMEA reports were required on all properties whose owners or operators applied for government loans to be used for exploration of various defense-related minerals, including uranium and thorium. These reports vary in type of information and quality; however, they generally provide accurate information on location, development, and host rock. Unfortunately, these reports are company confidential and are for New Mexico Bureau of Mines and Mineral Resources use only. They are cited in the occurrence descriptions as USBM files followed by year in parentheses.

Various mineral files and unpublished reports from the BLM, AML, and New Mexico State Inspector of Mines occassionally include location lists and descriptions of uranium and thorium occurrences. The DOE (Grand Junction and Albuquerque offices) provided the author with information from some of their comprehensive files on uranium and thorium occurrences, mines, and deposits. Additional information was obtained from New Mexico Bureau of Mines and Mineral Resources files.

Field reconnaissance of nearly 400 occurrences by the author during 1980-1983 provided accurate information on the geology and development. Most of these field investigations were reconnaissance only. All of the major uranium mining districts and areas were examined during the course of the field work.

Classification of Uranium and Thorium Deposits

A classification scheme which involves most types of uranium deposits was established by the NURE program (Mathews and others, 1979; Mickle, 1978; Mickle and Mathews, 1978). Uranium deposits in this scheme are characterized as (1) deposits in sedimentary rocks, (2) deposits in intrusive igneous and metamorphic rocks, (3) deposits in volcanic rocks, and (4) deposits of uncertain origin; they are further classified as to type of deposit (Table 2). This classification as described by Mathews and others (1979), Mickle (1978), and Mickle and Mathews (1978) is used in this report with a few exceptions. Uranium deposits in igneous and metamorphic rocks are subdivided into five types for the purposes of this report instead of the eight types proposed by the NURE classification (Table 2). Magmatic-hydrothermal, Authigenic, and Allogenic deposits are termed Hydrothermal-vein deposits in this report, and Contact-metasomatic and Autometasomatic deposits are termed Contact-metasomatic (Table 2). Many hydrothermal-vein deposits in this report probably belong to another type of deposit; however, insufficient information is available to adequately classify them otherwise than as Hydrothermal-vein deposits. Deposits in volcanic rocks are not subdivided as to type in this report, but are termed Volcanogenic deposits. Two additional deposits are differentiated in this report as Deposits of Uncertain Origin;

Table 2 - Classification of uranium and thorium deposits used by the U.S. Department of Energy (NURE program) and in this report

CLASS	TYPE (NURE)	TYPE (This Report)
Deposit in Sedimentary rocks	Sandstone roll-type tabular Beach (or river) Placer Sandstone Quartz-pebble conglomerate Marine black shale Phosphorite Lignite, coal, and nonmarine shale Evaporative precipitates-calcretes Limestone	Sandstone roll-type tabular Beach (or river) Placer Sandstone Quartz-pebble conglomerate Marine black shale Phosphorite Lignite, coal, and nonmarine shale Evaporative precipitates-calcretes Limestone
Deposits in igneous and metamorphic rocks	Orthomagmatic Pematitic Magmatic-hydrothermal Contact-metasomatic Autometasomatic Authigenic Allogenic Anatectic	Orthomagmatic Pematitic Hydrothermal-vein Contact-metasomatic Anatectic
Deposits in volcanic rocks	Initial-magmatic Pneumatogenic Hydroauthigenic Hydroallogenic	Volcanogenic deposits
Deposits of uncertain origin	Unconformity-related deposits Vein-type in sedimentary rocks Vein-type in metamorphic rocks	Unconformity deposits Vein-type in sedimentary rocks Vein-type in metamorphic rocks Deposits in diatremes Breccia-pipe deposits

they are Deposits in diatremes and Breccia-pipe deposits. Deposits in diatremes are described by Scarborough (1981), Shoemaker (1956a), and Green and others (1980b). Deposits in breccia-pipes are described by Gornitz and Kerr (1970), Scarborough (1981), and Wylie (1963). This same classification is used to classify thorium deposits.

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It is difficult to acknowledge all of the people who have assisted and contributed time and materials during the course of this work. Foremost, I would like to thank Frank Kottlowski (Director of the New Mexico Bureau of Mines and Mineral Resources) for his support and encourgement throughout the term of this project. William Chenoweth (U.S. Department of Energy) acted as Technical Monitor of this project and provided much of the background information, production statistics, field notes, and general data. Harlen Holen (U.S. Department of Energy) also provided a large amount of information and materials.

My colleages at the New Mexico Bureau of Mines and Mineral Resources spent considerable time in discussions and field examinations of many areas. In particular, I would like to thank Dave Menzie, Robert Eveleth, Richard Chamberlin, Robert North, Donald Wolberg, Robert Weber, and Ron Broadhead for their assistance in the field. Lynn Brandvold and associates, and K. Babette Faris provided chemical analyses of samples collected in the field. In addition, discussions with Orin Anderson, Richard Chamberlin, and Robert Eveleth greatly enhanced my understanding of uranium mining and geology in New Mexico.

Several mining companies allowed field examination of their properties and some of the companies sent a geologist to accompany me in the field. In particular, I would like to acknowledge the help of Timothy Tessendorf (Reserve Oil and Minerals Corp.), Bob Lynn and Bob George (Anaconda), Al Zimmerman and Art Geabue (Kerr McGee Corp.), Torreon Olson (Todilto

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Various people read portions of this manuscript and their comments and criticisms are greatly appreciated; they include William Chenoweth and Harlen Holen (U.S. Department of Energy); James M. Barker, Ron Broadhead, Robert Eveleth, and Robert North (New Mexico Bureau of Mines and Mineral Resources); Craig Goodknight (Bendix Field Engineering Corp.); and Robert Peets and Keith Rosvold (Western Nuclear). The assistance of Vivian Gomez and Roger Leaf (New Mexico Institute of Mining and Technology) in indexing, proof-reading, and cataloging is greatly appreciated.

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Uranium and Thorium Production in New Mexico

Uranium production in New Mexico has surpassed yearly production from all other states since 1956 (U.S. Department of Energy, Statistical data of the uranium industry, 1969 to 1982). Over 200 mines (Appendix 3) in New Mexico have produced 162,010 tons (146,973 metric tons) of U_3O_8 from 1948 to 1982, 40% of the total United States uranium product (Table 3). Over 99% of this production has come from sedimentary deposits in the Grants uranium district in northwestern New Mexico. Uranium production also has come from sandstone, vein-type, hydrothermal-vein, and pegmatite deposits scattered throughout the state (Fig. 1).

From 1948 through 1970, the U.S. Atomic Energy Commission purchased most of the uranium ore produced in New Mexico, although minor amounts of ore may have been sold to chemical companies. Production statistics for individual mines from 1948 through 1970 have been released to the public; these production figures are tabulated in Appendix 3 (Table 3-1). Yearly production figures have been compiled by the U.S. Atomic Energy Commission (AEC) and succeeding agencies, the U.S. Energy Research and Development Administration (ERDA) and the U.S. Department of Energy (DOE); they are tabulated in Table 3. Production by area and host rock is given in Table 4.

Table 3 - Uranium ore production in New Mexico from 1948 to 1982 (U.S. Department of Energy, Statistical Data of the Uranium Energy, 1968-1982; U.S. Atomi Energy Commission ore and mill receipts tabulated by William Chenoweth and Elizabeth Learned, USDOE). 1) Includes only ore mined in New Mexico; does not include production from in-situ leach, mine water, or heap leach. Ore production from 1948 to 1970 includes only "pay" and "no-pay" ore received by the AEC. The AEC did not pay for shipments less than 0.10% U_3O_8; hence, these shipments were known as "no-pay" ores. 2) Includes production from in-situ leach, mine water, and heap leach. Also includes some concentrate production that was mined out of state. 3) Yearly average price of uranium not spot or market price. 4) Number of producing properties may vary in accordance with the definition of a particular property. For example, Anaconda's Jackpile-Paguate mine is considered one property. 5) New Mexico 1948 and 1949 production was entirely from Carrizo Mountains in San Juan County.

	ORE RECEIVED AT MILLS AND BUYING STATIONS[1]					CONCENTRATE PRODUCTION FROM MILLS OPERATING IN NEW MEXICO[2]					
Calendar year	Tons of U_3O_8 in New Mexico	Grade % U_3O_8	Tons of U_3O_8 in U.S.	Grade % U_3O_8	New Mexico as % U.S. total	Tons of U_3O_8 in New Mexico	Tons of U_3O_8 in U.S.	New Mexico as % U.S. total	Average price per pound U_3O_8 (dollars)[3]	Number of properties in New Mexico	Number of operators
1948	4[5]	0.29	80	0.26	5	—	102	—	7.50	8	1
1949	8[5]	0.17	500	0.29	2	—	177	—	8.77	12	1
1950	11	0.32	800	0.32	1	—	459	—	10.76	19	12
1951	11	0.24	1,100	0.32	1	—	766	—	10.30	19	17
1952	34	0.20	1,300	0.30	3	—	874	—	11.85	37	31
1953	215	0.25	2,300	0.31	9	9	1,163	1	12.27	50	36
1954	666	0.35	3,500	0.32	19	181	1,700	11	12.43	59	45
1955	618	0.23	4,400	0.29	14	847	2,784	30	11.94	68	58
1956	2,888	0.26	8,400	0.28	34	2,891	5,958	49	11.10	58	51
1957	2,585	0.22	9,800	0.27	26	2,534	8,482	30	9.82	55	49
1958	4,032	0.21	14,000	0.27	29	3,604	12,437	29	8.86	53	44
1959	6,982	0.21	17,400	0.25	40	6,772	16,239	42	8.64	60	41
1960	7,892	0.21	18,800	0.23	42	7,760	17,637	44	8.35	57	41
1961	7,848	0.22	18,500	0.23	42	7,750	17,348	45	7.88	57	34
1962	7,894	0.23	17,100	0.24	46	7,293	17,008	43	7.92	57	30
1963	5,132	0.22	14,700	0.25	35	5,512	14,217	39	8.00	46	33
1964	4,716	0.23	13,900	0.26	34	4,747	11,846	40	8.00	42	29
1965	4,709	0.23	10,500	0.24	44	4,591	10,442	44	8.00	36	20
1966	4,892	0.24	9,900	0.23	48	5,076	10,589	48	8.00	41	21
1967	5,816	0.21	10,900	0.21	53	5,933	11,253	53	8.00	33	13
1968	6,443	0.20	12,800	0.21	50	6,192	12,368	50	8.00	31	12
1969	6,210	0.20	12,600	0.20	49	5,943	11,609	51	5.86	29	11
1970	6,057	0.21	13,100	0.20	46	5,771	12,905	45	5.56	32	12
1971	5,594	0.23	13,100	0.21	43	5,305	12,273	43	—	29	9
1972	5,722	0.25	13,900	0.21	41	5,464	12,900	42	—	34	11
1973	4,984	0.23	13,800	0.20	36	4,634	13,235	35	7.10	26	6
1974	5,435	0.18	12,600	0.18	43	4,951	11,528	43	7.90	23	5
1975	5,484	0.18	12,300	0.16	45	5,191	11,600	45	10.50	25	8
1976	6,485	0.19	14,000	0.15	46	6,059	12,747	48	16.10	32	14
1977	7,586	0.18	16,700	0.15	45	6,779	14,940	45	19.75	36	12
1978	9,371	0.15	20,200	0.13	46	8,539	18,490	46	21.60	41	15
1979	8,198	0.12	20,700	0.11	40	7,423	18,730	40	23.85	43	13
1980	8,160	0.12	23,300	0.12	35	7,751	21,850	35	28.15	50	14
1981	6,573	0.12	19,600	0.11	34	6,206	19,240	32	28.70	39	13
1982	3,755	0.18	10,520	0.12	36	3,906	13,430	29	32.41	28	10
TOTAL	163,010		407,100		40	155,614	379,326	41			

Table 4 - Uranium production in New Mexico from 1948 to 1982 by area and host rock.

AREA	HOST FORMATION	PRODUCTION (Pounds of U_3O_8)	PERIOD
COLORADO PLATEAU			
Nacimiento, Farmington	Ojo Alamo, Fruitland, Dakota, Morrison, Todilto, Chinle, and Cutler Formations	2,298	1954-1959
Shiprock			
Carrizo Mountains and Sanostee	Salt Wash Member[1]	160,772	1948-1968
Sanostee	Recapture Member[1]	335,000[2]	1951-1982[5]
	Todilto Limestone	14	1954
Grants uranium district	Dakota Sandstone[3]	512,917	1951-1970
	Morrison Formation (Brushy Basin and Westwater Canyon, and Recapture Members, Jackpile sandstone, and Poison Canyon Sandstone)	313,690,000[2]	1951-1982
	Breccia Pipe[3]	134,014	1953-1956
	Todilto Limestone[4]	6,736,000[2]	1950-1982
	Mine Water	4,113,000[2]	1963-1982
Red Basin area, Catron County	Mesa Verde Group (Crevasse Canyon Formation)	1,194	1954-1957
	SUB TOTAL	325,685,209	1948-1982
BASIN AND RANGE[3]			
Santa Fe, Catron, and Lincoln Counties	Tertiary intrusives and volcanics (hydrothermal-vein)	27,485	1955-1966
Socorro and Sierra Counties	San Andres Limestone, Popotosa Formation, and Madera Formation (vein-type)	63,250	1953-1956
Grant, Dona Ana, and Hildago, Counties	Precambrian granites, Magdalena Group, and U-Bar Formation (hydrothermal-vein)	1,416	1953-1958
Socorro, Sierra, and Santa Fe Counties	Abo, Madera, Baca, San Jose, and Popotosa Formations (sandstone)	409	1955-1963
	SUB TOTAL	92,560	
GREAT PLAINS[3]			
Harding, Mora, Quay, and San Miguel Counties	Chinle, Sangre de Cristo, and Morrison Formations (sandstone)	183	1954-1958
SOUTHERN ROCKY MOUNTAINS[3]			
Rio Arriba and Taos Counties	Precambrian granite (hydrothermal-vein)	15	1954-1957
Rio Arriba and San Miguel Counties	Precambrian pegmatites	34	1954-1956
	SUB TOTAL	49	
	TOTAL	325,778,001	1948-1982

1 - member of the Morrison Formation

2 - approximate figures (rounded to the nearest 1,000 pounds)

3 - statistics in Appendix 3

4 - some ore mined from Entrada Sandstone

5 - intermittently during these years

Most of the uranium production in New Mexico has come from the Morrison Formation in the Grants uranium district in McKinley and Cibola (formerly Valencia) Counties (McLemore, 1983a), mainly from the Westwater Canyon Member. Annual production in New Mexico increased steadily from 1948 to 1956, from 1957 to 1960, from 1965 to 1968, and from 1973 to 1979. Peak production was attained in 1978, with a record yearly production of 9,371 tons (8,501 metric tons) of U_3O_8 shipped to mills and buying stations (Table 3).

Unfortunately, production statistics for radium and thorium are unavailable. Radium was produced from the Carrizo Mountains in San Juan County (U.S. Atomic Energy Commission files, 1942-1948); the White Signal district in Grant County (Gillerman, 1964); and the Scholle district in Torrance, Socorro, and Valencia Counties (U.S. Bureau of Mines unpublished files, 1949). Exact production figures are unknown. Thorium has never been commercially produced in New Mexico, except perhaps as a by-product of bastnaesite, samarskite, and monazite production from the Gallinas Mountains, Lincoln County (Griswold, 1959), and the Petaca district, Rio Arriba County (Jahns, 1946). Tonnages, if any, of thorium recovered from these shipments are unknown.

Uranium and Thorium Occurrences in New Mexico

Introduction

Uranium and thorium in New Mexico occurs in rocks of all ages, from Precambrian granites to Recent travertine deposits (Appendix 1). Radioactive occurrences are found in sandstones, coals, lignites, shales, limestones, intrusive igneous and metamorphic rocks, hydrothermal-veins, volcanic rocks, and breccia pipes. Uranium and thorium in New Mexico are associated with copper, selenium, molybdenum, iron, fluorite, barite, rare-earth elements, nickel, zinc, lead, and silver deposits. Radioactive occurrences are found in over 100 formational units and in all but two counties in New Mexico. Uranium and thorium occurrences are found in all 1- by 2-degree topographic quadrangles (Fig. 2) and all four geographic provinces (Fig. 3) in New Mexico.

The majority of uranium occurrences in the state are in sandstones of the Jurassic Morrison Formation in the Grants uranium district (Fig. 1). The Grants uranium district is located along the southern edge of the Colorado Plateau and is divided into six subdistricts or areas. These subdistricts or areas are Laguna, Marquez-Bernabe Montaño, Ambrosia Lake, Smith Lake, Church Rock, and Nose Rock (Fig. 4).

Thorium occurrences are found in beach-placer sandstone deposits, pegmatites, carbonatites, and hydrothermal-veins (Appendix 1). They occur in the Chico Hills area, Colfax County; Sangre de Cristo and Tusas Mountains, northern New Mexico; San

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES

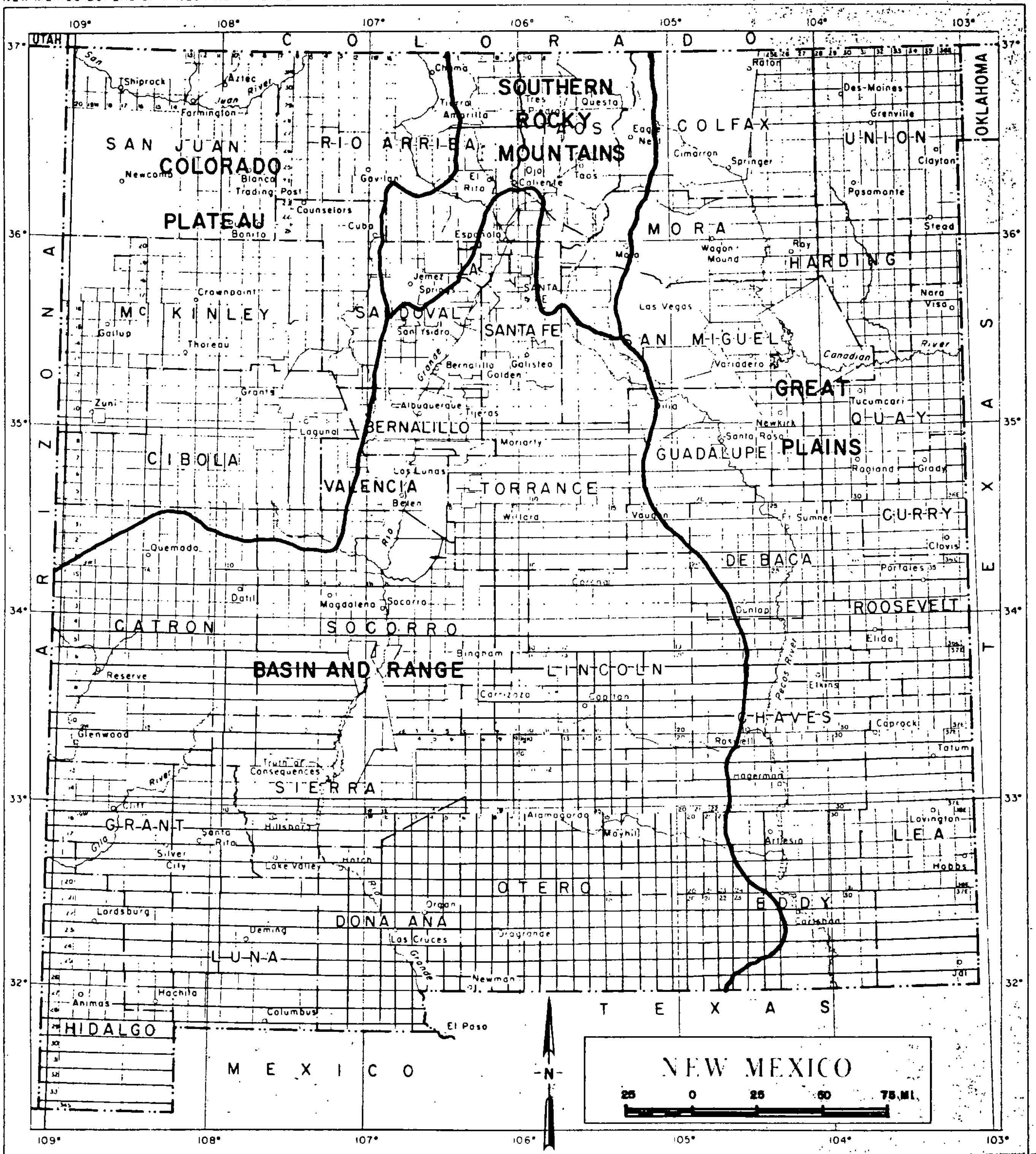


FIGURE 3—GEOGRAPHIC PROVINCES IN NEW MEXICO

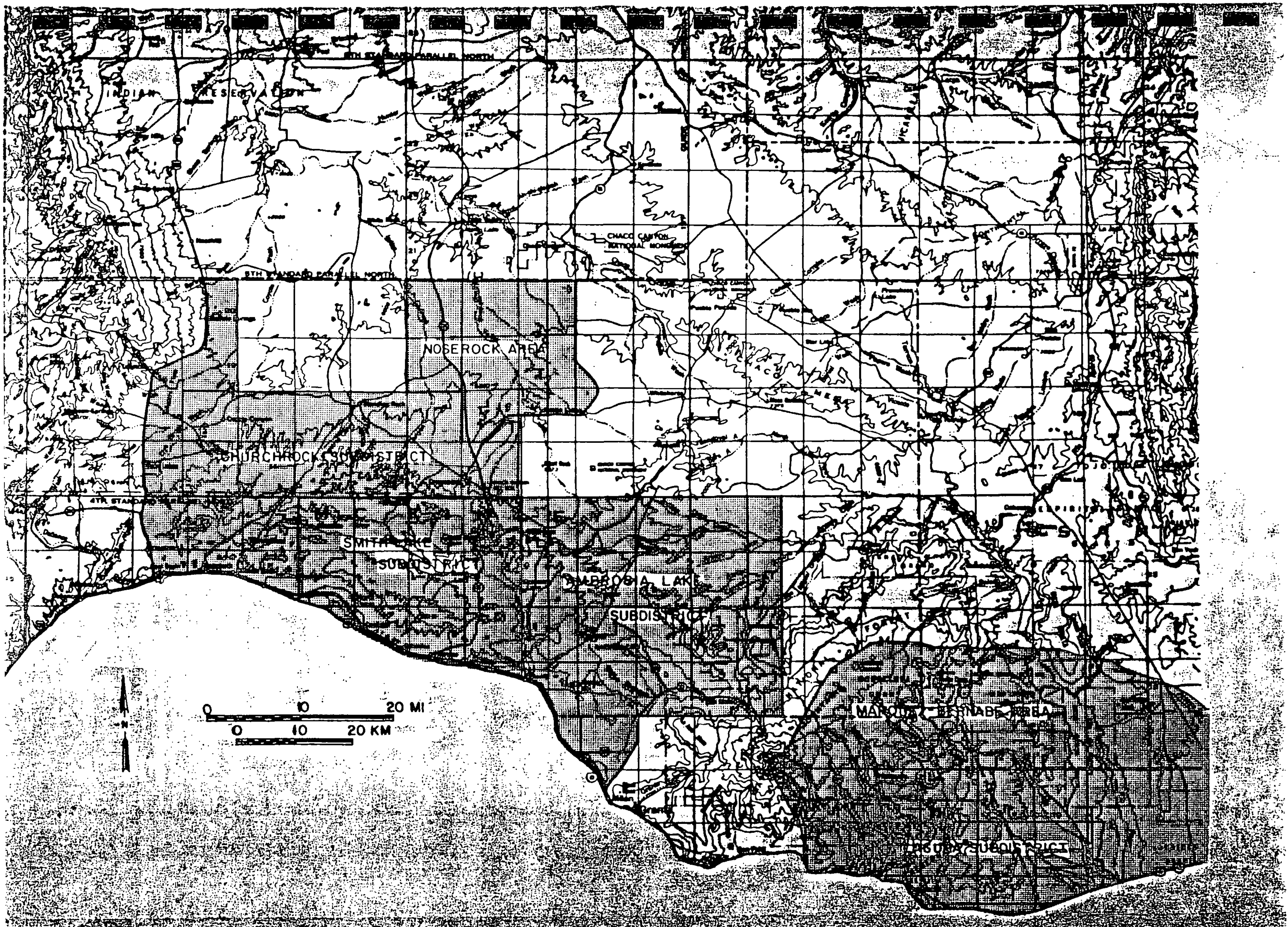


FIGURE 4–SUBDISTRICTS AND AREAS IN THE GRANTS URANIUM DISTRICT, NEW MEXICO

Juan Basin; Monte Largo Hills, Bernalillo County; Lincoln County; Burro Mountains, Grant County; Rio Grande area, Socorro and Sierra Counties; and Cornudas Mountains, Otero County (Fig. 5). No thorium has been produced in New Mexico except possibly as a by-product of production from pegmatites.

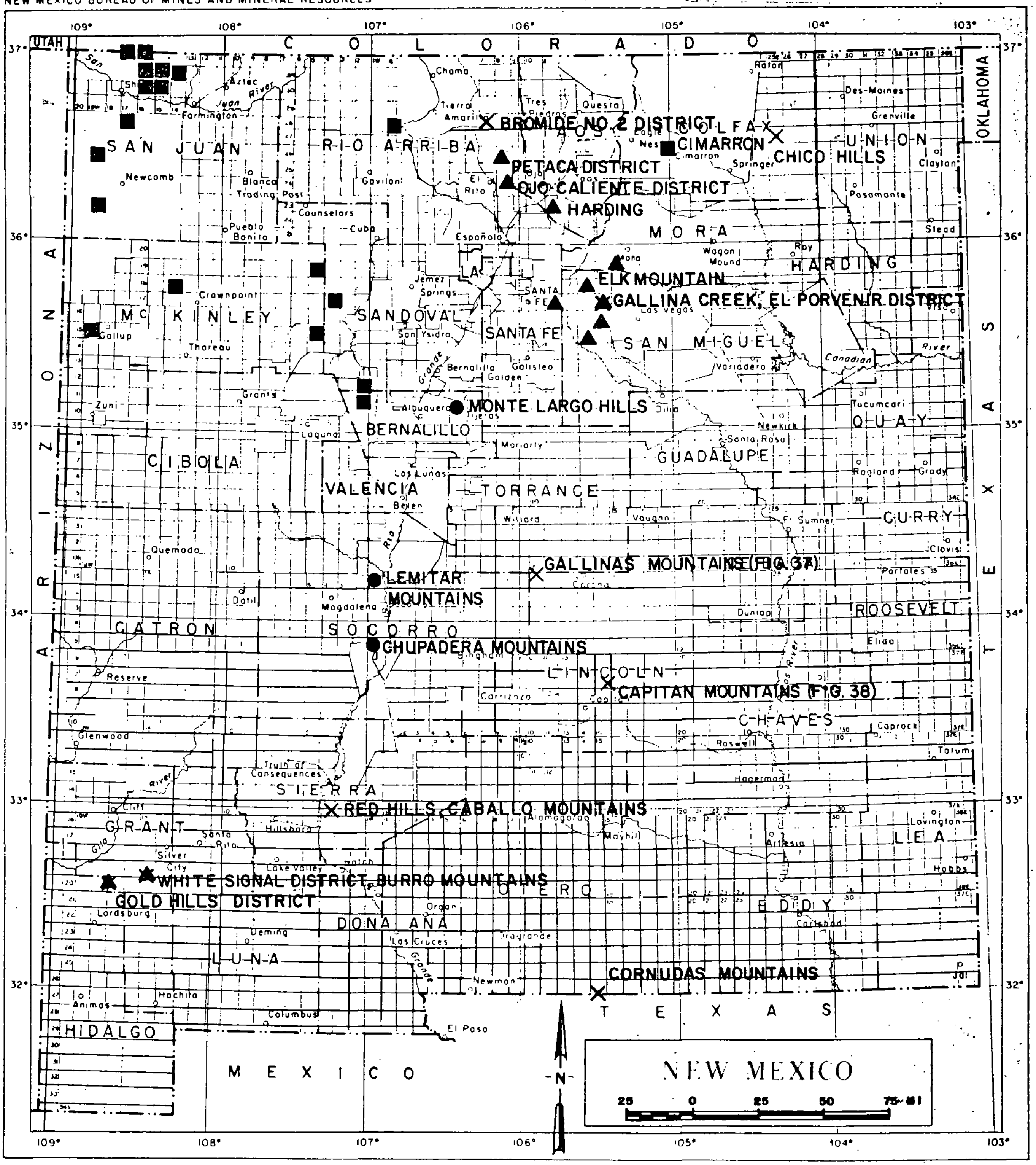
Over 1,300 uranium and thorium occurrences are individually described in Appendix 1 and located in Figure 1 and various county maps (Figs. 1-5 to 1-33). Uranium prospects, deposits, and mines in the Grants uranium district are located on 30- by 60-minute maps (Figs. 6-9) and additional district maps are included (Figs. 11-13). Uranium occurrences in areas outside of the Grants uranium district are plotted on additional maps as indicated.

Limestone Deposits in the Jurassic Todilto Limestone and Adjacent Units

Over 100 uranium occurrences are found in the Jurassic Todilto Limestone (Appendix 1), 42 of which have produced ore (Appendix 3). Over 6,736,000 pounds (3,055,000 kilograms) of uranium have been produced from the Todilto Limestone and adjacent units from 1950 to 1982, about 2% of the total uranium production in New Mexico (Table 4). The majority of these occurrences are in the Grants uranium district, although minor occurrences are found in the Chama Basin-Llaves area in Rio Arriba County, Nacimiento Mountains in Sandoval County, and the Sanostee subdistrict of the Shiprock district in San Juan County. Two occurrences, Reed Henderson #1 in the Sanostee subdistrict

FIGURE 5-THORIUM OCCURRENCES IN NEW MEXICO

NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES



X THORIUM VEINS

▲ PEGMATITES

● CARBONATITE

■ BEACH-PLACER SANDSTONES (FIG. 25)

and Box Canyon in the Chama Basin (Appendix 3), have produced minor quantities of uranium ore in the 1950's. Although the bulk of this mineralization occurs in the Todilto Limestone, minor mineralization occurs also in the basal portion of the overlying Summerville Formation and at the top of the underlying Entrada Sandstone (Fig. 10).

The initial discovery of uranium mineralization in the Grants uranium district was in 1950 by Paddy Martinez in the Todilto Limestone. Uranium minerals were known to occur in the Todilto Limestone since the early 1920's (Melancon, 1963) and in 1948 (C. T. Smith, 1954), but their significance was not realized until Paddy Martinez's discovery. Paddy Martinez discovered tyuyamunite at what is now known as the Haystack-Section 19 mine.

The Todilto Limestone consists of two informal units, a basal limestone and an upper gypsum-anhydrite member. The basal limestone is 5-30 ft (1 to 9 m) thick and present everywhere in the Todilto depositional basin. This unit consists of three zones, a basal platy or laminated zone, a crinkly or crenulated zone, and an upper massive zone. The overlying gypsum-anhydrite member reaches a maximum thickness of 170 ft (32 m) and is present in the central portions of the Todilto basin. The gypsum-anhydrite member is locally mined and constitutes much of the gypsum and anhydrite resources in New Mexico (G. S. Austin and others, 1982). The gypsum-anhydrite member is present in the Laguna area, but is absent elsewhere in the Grants uranium district. However, this unit is penetrated by drill holes about 8 mi (13 km) north of the Poison Canyon area (Hilpert, 1969, p. 95).

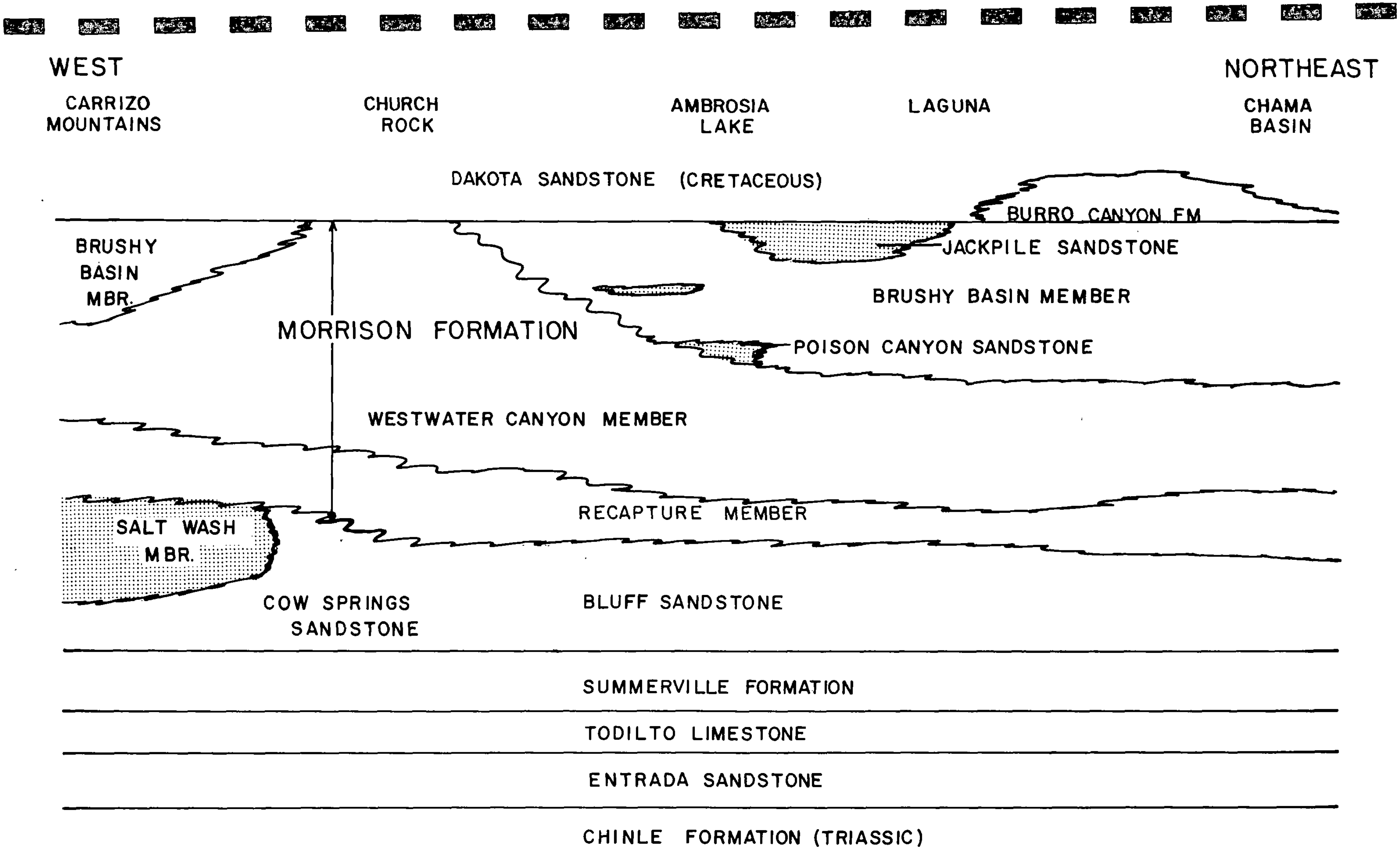


FIGURE 10-STRATIGRAPHIC CORRELATIONS IN THE SAN JUAN BASIN.

The Todilto Limestone is deposited in a basin which occupies an area of about 34,000 mi^2 (88,060 km^2) in the San Juan Basin It is equivalent in age with the Pony Express Limestone Member of the Wanakah Formation in Colorado and the Curtis Formation in Utah (Green, 1982).

The actual depositional environment of the Todilto Limestone is controversial. The Todilto Limestone overlies the Entrada Sandstone, which consists of eolian dune and inland interdune sequences; fluvial units are absent. The overlying Summerville Formation consists of eolian dune and fluvial sabkha sequences. It is uncertain whether the origin of the Todilto Limestone was marine or a nonmarine. The presence of the gypsum-anhydrite member and correlation with marine limestones of the Curtis Formation suggest a marine origin, an embayment or lagoon (Hines, 1976; B. L. Perry, 1963). However, the lack of confirmed marine fossils (Hines, 1976) and of dolomitic sequences (Green, 1982), the presence of varved sequences (R. Y. Anderson and Kirkland, 1960, 1966), and the coastal-continental environments of the Entrada Sandstone and Summerville Formations favor a lacustrine origin, a coastal sabkha environment (Rawson, 1980a, b), an enclosed saline lake, or a brackish-water lake connected to the sea (R. Y. Anderson and Kirkland, 1960). Recent isotopic evidence supports a marine origin (Ridgley and Goldhaber, 1983).

Uranium mineralization is found only where the gypsum member is absent (Hilpert, 1969), and the mineralization may extend into the overlying Summerville Formation or underlying Entrada Sandstone. The majority of the Todilto Limestone deposits are found along outcrops of the Todilto Limestone in the Poison Canyon and Thoreau areas, although mineralized drill holes in the Todilto Limestone also occur in the Ambrosia Lake area (Young, 1960, p. 270; Irving Rapaport, Four Corners Exploration Company, written commun., 11/11/82; Harlen Holen, U.S. DOE, written commun., 1983). Uranium deposits are tabular and irregular in shape, similar to sandstone deposits. They range in size from a few feet to 100's of feet wide and long and up to 20 ft (16 m) thick. Three types of mineralization are found; unoxidized primary deposits, oxidized primary deposits, and secondary deposits (Gabelman, 1970). Most of the limestone deposits occur along the flanks or axes of intraformational folds, unlike sandstone deposits. Locally, the limestone deposits appear to align in trends subparallel to the sandstone deposits (Fig. 11). Uranium mineralization occurs throughout the entire thickness of the Todilto Limestone. The largest ore bodies occur where the intraformational folds are clustered and have a similar trend (Hilpert, 1969). Pb/U apparent age dates suggest that primary mineralization occurred during or just after deposition of the Todilto Limestone (Berglof, 1969; D. S. Miller and Kulp, 1963).

The origin of the ore-controlling intraformational folds is controversial (Hines, 1976; Hilpert, 1969). These folds are restricted to the Todilto Limestone and to the basal portion of the Summerville Formation; overlying beds are flat-lying. The folds vary in size and shape. They tend to cluster in east-west or north-south trends. Open and closed anticlines (Fig. 14), recumbent folds, and chevron folds (Fig. 15) are common. Their axes show little, if any, relationship to regional structure.

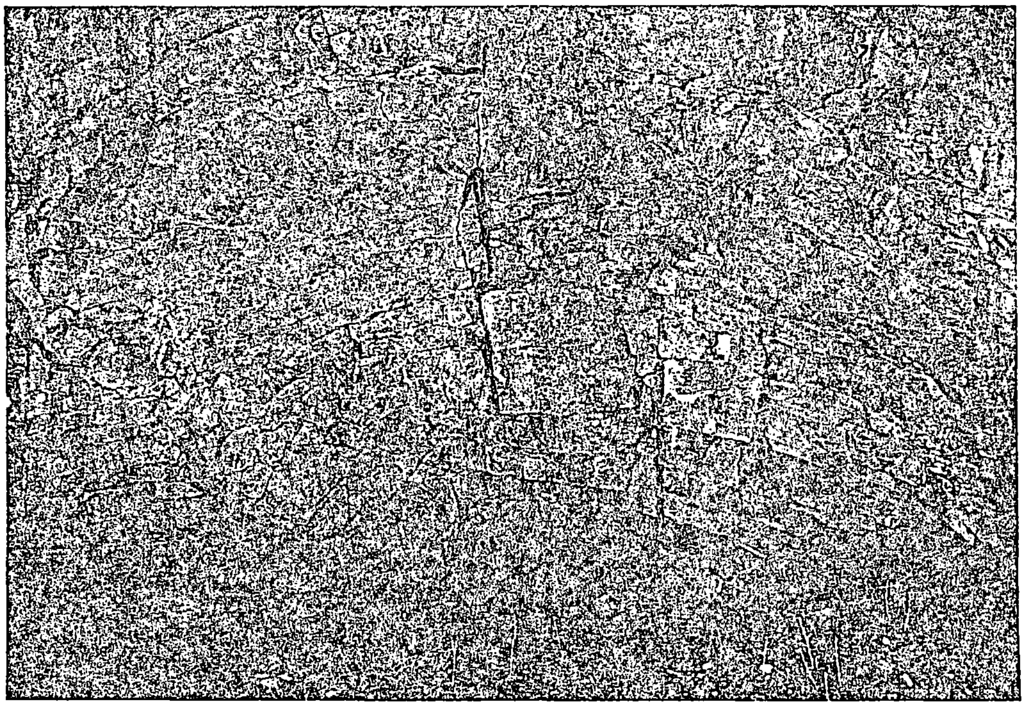


Figure 14 - Intraformational fold in the Todilto Limestone at the Haystack open pit. This fold may have resulted from algal structures. Uranium mineralization is disseminated within the limestone and along the fractures and bedding planes.

Rapaport and others (1952a, b) and Hilpert and Moench (1960) attribute these folds to soft sediment slumping or creeping down a depositional slope or the flanks of anticlines. Gabelman (1956b) attributes the folds to volumetric changes due to dehydration and diagenesis. B. L. Perry (1963) suggests that the folds are a result of differential loading and compaction near subsiding reef or biohermal structures. Parasitic or drag folds on tectonic features may have produced the intraformational folds (Hines, 1976). However, none of these theories is consistent with all of the field observations (Hines, 1975; Green, 1982).

A theory proposed by Rawson (1980a, b) and Green (1982) and modified by the author is consistent with many of the field observations, but certainly is not the only viable theory possible. The Todilto Limestone was deposited in an arid climate, in an enclosed saline or brackish-water lake; the exact setting of the Todilto basin is not critical to this model. Periodic drying of the lake enabled deposition of the gypsum member. Simultaneously, Summerville dunes slowly migrated over Todilto limey muds and algal mats, compacting and warping the Todilto beds, thereby forming the intraformational folds. Continued migration of Summerville dunes locally continued to deform the underlying Todilto muds; forming convolute laminations, mounds, rolls, folds, and anticlines and synclines (Green, 1982). The presence of a depositional slope basinwards enhanced migration of the Summerville dunes and deformation of the underlying Todilto beds. Hydraulic and evaporative pumping of uraniferous groundwater in the underlying permeable Entrada

Figure 15 - Chevron fold in the Todilto Limestone at the Section 25 open pit. Height of pit wall is approximately 12 ft (3 m).

Sandstone brought the uraniferous waters into the organic-rich layers of the Todilto mud. The intraformational folds acted as a structural trap for uranium-bearing waters. The Todilto mud would be permeable only until the muds dried, therefore this hydraulic pumping occurred in a relatively short period of time. However, as the deformed muds dried and turned into impermeable limestones, they fractured and faulted where folded. These fractures provided the permeability required for additional hydraulic and evaporative pumping to continue after diagenesis. The hydraulic and evaporative pumping could not occur where the gypsum member was deposited, since the gypsum acted as a cap. Subsequent oxidation and remobilization of primary uranium deposits occurred possibly during Tertiary times, as suggested by Saucier (1980).

Additional uranium deposits are likely to occur in the Todilto Limestone in the Grants uranium district (Green and others, 1980b, c; U.S. Department of Energy, 1980). These undiscovered deposits probably will be similar in size and shape to the known Todilto deposits. Numerous holes beyond 1,000 ft (305 m) depths have been drilled in the Ambrosia Lake area. A surprising number of these deep drill holes indicates mineralization in the Todilto Limestone. Additional work is needed to refine the model of Green (1982) and Rawson (1980a, b) and to adequately delineate the margins of the Todilto basin and the extent of the Summerville dunes.

Outside of the Grants uranium district, economic ore deposits in the Todilto Limestone are scarce (Appendix 1).

Production from a few of these deposits (Appendix 3) has been small and generally of low grade.

Sandstone Deposits in the Jurassic Morrison Formation

Grants uranium district

The majority of the uranium deposits in New Mexico occur in sandstones of the Morrison Formation. Over 313,690,000 lbs (142,287,391 kg) of U_3O_8 have been produced from this formation from 1948 through 1982, over 96% of the total uranium production in New Mexico (Table 4). In the Grants uranium district the Morrison Formation consists of three members, in ascending order: the Recapture, Westwater Canyon, and Brushy Basin. The ore-bearing Salt Wash Member of the Morrison Formation in the Carrizo Mountains, Shiprock district, is absent in the Grants uranium district (Fig. 10).

The Recapture Member unconformably overlies the Cow Springs and Bluff Sandstones in the Grants uranium district (Fig. 10). This member typically consists of 50 to over 200 ft (15 to 61 m) of alternating maroon and gray shales, siltstones, and fine-grained sandstones (Hilpert, 1963, 1969). Low- to medium- energy fluvial sandstones and interbedded overbank siltstones lie adjacent to dune sandstones and sabkha siltstones (Green, 1975). Near the top of the Recapture Member a disconformity separates the eolian-sabkha sequence from the overlying fluvial-lacustrine sequence. This disconformity is locally marked by a thin basal lag-conglomerate (Green, 1975, 1980). Many of the uranium occurrences in the Recapture Member are found at or above this disconformity.

The Westwater Canyon Member is the major uranium-bearing sequence in New Mexico (Fig. 10). This member is 50 to 300 ft (15 to 91 m) thick and consists of reddish-brown or gray arkosic sandstones and interbedded gray and green to greenish-gray shales (Hilpert, 1963, 1969). Sandstones exhibit features typical of braided stream environments, whereas siltstones and shales are typical of overbank and lacustrine deposits (Turner-Peterson and others, 1980).

Shales of the Brushy Basin Member locally intertongues with the underlying Westwater Canyon Member (Fig. 10). The Brushy Basin Member is 100 to over 500 ft (30 to 152 m) thick (Hilpert, 1963, 1969) and consists of light greenish-gray shales and mudstones and a few interbedded sandstones lenses. The basal sandstone present in the Ambrosia Lake-Poison Canyon area is the Poison Canyon sandstone (of economic usage) and is locally mineralized. The Poison Canyon sandstone exhibits features typical of a distal braided or low-energy braided stream with adjacent overbank and lacustrine sediments, and is locally similar to the upper Westwater Canyon sandstones. Correlations of the Poison Canyon sandstones away from the Ambrosia Lake-Poison Canyon area are difficult due to pinchouts and shale splits. It is unclear which sandstone lenses elsewhere in the Grants uranium district would correlate with the Poison Canyon sandstone in the Ambrosia Lake-Poison Canyon area. For this reason, the term Poison Canyon sandstone should be restricted to the basal sandstone in the Ambrosia Lake-Poison Canyon area, although some authors have extended this terminology elsewhere in the Grants uranium district.

The Jackpile sandstone (of economic usage) occurs at the top of the Brushy Basin Member and is present only in the Laguna area (Fig. 10). This sandstone is truncated by the Cretaceous unconformity and is overlain by the Cretaceous Dakota Sandstone. It consists of a thick arkosic sandstone with minor interbeds or lenses of shale. Features typical of a braided stream environment are common (Baird and others, 1980; Jacobsen, 1980; Moench and Schlee, 1967). This major uranium-bearing unit occurs in a northeast-trending zone as much as 13 mi (21 km) wide, 33 mi (53 km) long, and up to 200 ft (61 m) thick (Moench and Schlee, 1967). South of the Laguna area the Jackpile sandstone is truncated, whereas north of the Laguna area it is split into two or more sandstones. The Jackpile sandstone is the major uranium-bearing horizon in the Laguna area. Only a few drill holes have penetrated the Westwater Canyon Member to ascertain whether it contains any mineralization.

Two types of uranium ore occur in the Grants uranium district; they are primary tabular and redistributed ore (Granger and others, 1961; Squyres, 1972). Primary tabular ore bodies are also known as trend or prefault ore. Redistributed ore bodies are known as stack or post-fault ore. In addition, redistributed ore can be differentiated as (1) fracture-controlled (stack), or (2) geochemical cell-controlled (roll-type). A third type of mineralization may also be present as relict or remnant primary ore (D. A. Smith and Peterson, 1980).

Primary tabular ore bodies occur as (1) flat-lying pods, (2) lenses, and (3) blankets all of which may be locally subparallel to bedding structures or cut across them. Local distribution of ore may be influenced by sedimentary features such as minor disconformities, bedding planes, cross-stratification, channels, or sandstone-shale interfaces. The peneconcordant ore deposits typically align in regional trends (Fig. 11-13), but may be difficult to predict on a local scale. These ore bodies tend to be dark gray to black and are characterized by a sharp boundary with unmineralized sandstone. They are irregular in shape and consist of thin, high-grade (greater than 0.20% U_3O_8), multiple lenses or ore pods. They are offset by Laramide faulting (hence prefault) and are considered the first stage of mineralization. In the Ambrosia Lake area, ore bodies in the Westwater Canyon Member tend to rise stratigraphically in a basinward direction (Santos, 1963; Granger, 1968). Some of this primary ore may have been originally deposited by geochemical cell processes. Uranium is directly associated with organic material referred to as humates (Leventhal, 1980; Webster, 1983), and may be enriched in V, Mo, and Se (Spirakis and others, 1981). Petrographic relationships, chemistry, and uranium distribution imply that uranium was introduced into the sediments after the organic matter was emplaced, but before compaction (Webster, 1983). Halos of Mo and Se may surround uranium mineralization (Squyres, 1972). Vanadium is generally less than uranium in concentration, whereas Mo may occur in sufficient quantities to hamper milling operations. Kerr McGee Nuclear Corp. added a circuit to recover Mo as a by-product in order to reduce its amount in the milling circuit. Homestake recovers V at their mill.

Redistributed ore bodies occur as discordant, asymmetrical, and irregular bodies that have been mobilized and reconcentrated by geochemical processes along fractures and faults or along the oxidation boundary (roll-type). These ore bodies vary in color from brownish-gray to light gray and are characterized by a gradational boundary with unmineralized sandstones. These ore bodies cut across sedimentary structures and stratification. They occur at the interface between oxidized red and reduced gray sandstones, but are not always fracture controlled. Fracture-controlled ore bodies tend to occur in thick multiple horizons and may be low in organic material (humates) and Mo. Se may be enriched throughout the ore deposit, but more commonly occurs along the interface between mineralized and barren sandstone (Fishman and Reynolds, 1983; Spirakis and others, 1981). Roll-type deposits may be difficult to distinguish from primary tabular ore bodies that have been oxidized (S. S. Adams and Saucier, 1981) or otherwise partially redistributed early in the mineralization process. Recycling of uranium by geochemical solutions may be occurring presently.

Relict or remnant ore pods in reduced sandstones surrounded by oxidized sandstones occurs locally updip from roll-type deposits (D. A. Smith and Peterson, 1980; Ristorcelli, 1980; S. S. Adams and Saucier, 1981). Occasionally, relict ore bodies may be in part or almost completely destroyed by subsequent oxidizing fluids leaving ghost ore bodies (Holen, 1982b; S. S. Adams and Saucier, 1981).

The timing and sequence of mineralization events in the Grants district is important to understand these deposits.

Geochronologic studies provide a timing of events that is consistent with many field observations. The most common dating method employed is the Pb/U isotopic dating of uranium minerals (Berglof, 1969; Ludwig and others, 1977; 1982; Brookins, 1981b), although Rb/Sr isochron dating of clay minerals may be more reliable (Brookins, 1975, 1980). Fission-track dating methods have recently been employed on quartz grains from sandstones at the Mariano Lake ore bodies (Rosenberg and Hooper, 1982); however, the reliability of this dating method needs to be further demonstrated. K/Ar dating of clay minerals has proven to be unreliable in view of Rb/Sr isochron studies (Brookins, 1975; Brookins, Lee, and Shafiquallah, 1977). A summary of the various age dates obtained of uranium mineralization in the Grants uranium district is presented in Table 5; unreliable K/Ar dates are not included.

The Jurassic Todilto Limestone was deposited in Late Jurassic times prior to deposition of the Morrison Formation, at about 150-160 m.y. ago (Berglof, 1969). The Pb/U apparent age dates of Todilto uranium mineralization in the Ambrosia Lake subdistrict range from 78 to 164 m.y. (Berglof, 1969; Miller and Kulp, 1963). Most of the Pb/U apparent age dates are discordant (Table 5); however, a few age dates are nearly concordant and suggest that the age of mineralization is about 130-150 m.y. These age dates suggest that mineralization occurred during or immediately after deposition of the Todilto Limestone; they are consistent with theories presented earlier by Green (1982) and Rawson (1980a, b). Mineralization in the Todilto Limestone is

Table 5 - Isotopic and fission-track age dates of uranium mineralization in the Grants uranium district.

DISTRICT OR MINE	Rb/Sr ISOCHRON AGE (m.y.)	$^{206}Pb/^{238}U$ APPARENT AGE (m.y.)	$^{207}Pb/^{235}U$ APPARENT AGE (m.y.)	FISSION-TRACK AGE (m.y.)	U-SERIES METHOD (open system)	REFERENCE
JURASSIC TODILTO LIMESTONE						
Barbara J #2	-	118±2	135±5	-	-	Berglof (1969)
#2	-	105±2	164±5	-	-	
#3	-	153±3	154±4	-	-	
#3	-	148±3	148±4	-	-	
Section 25	-	147±3	150±4	-	-	
25	-	146±3	150±4	-	-	
Zia	-	131±3	138±4	-	-	
Hanosh	-	145±3	152±4	-	-	
Faith	-	114±2	153±4	-	-	
	-	111±2	154±3	-	-	
F-33	-	131±3	147±4	-	-	
" (pitchblende)	-	78±5	107±6	-	-	Miller and Kulp (1963)
Haystack Butte (pitchblende)	-	255±5	175±5	-	-	
Flat Top (uranophane)	-	2.8	3.2	-	-	Brookins (1981b)
	-	4.0	4.2	-	-	
	-	2.7	2.8	-	-	
	-	6.6	7.4	-	-	
JURASSIC MORRISON FORMATION						
Ambrosia Lake - Sections 23, 35	139±10 (9 samples)	-	-	-	-	Brookins (1975, 1980), Lee and Brookins (1978)
Smith Lake - Mariano Lake mine	139±13 (9 samples)	-	-	-	-	
Jackpile-Paguate mine	113±7 (22 samples)	-	-	-	-	Brookins (1975, 1980), Lee and Brookins (1978, 1980
Jackpile-Paguate mine (cofinite)	-	81±2	94±3	-	-	Nash and Kerr (1966), Berglof (1969)
Woodrow mine (cofinite)	-	88±2	90±3	-	-	Nash (1968), Berglof (1969
N.E. Church Rock mine (UNC)	-	68.7±0.5	95.2±1.0	-	-	Ludwig and others (1982)
Smith Lake	30±90 (scattered data)	-	-	-	-	Brookins (1980)
Smith Lake - Mariano Lake mine	-	-	-	13.8–15.9	-	Rosenberg and Hooper (1982
	-	-	-	6.6–6.7	-	
Ambrosia Lake (uranophane)	-	8.33	8.35	-	-	Brookins (1981b)
N.E. Church Rock Mine (KM)	-	7.84±0.04	9.56±0.06	-	-	Ludwig and others (1982)
	-	1.01–1.12 (3 samples)	0.982–1.07	-	-	
Church Rock Mine	-	0.974±0.546	0.776±1.140	-	-	
N.E. Church Rock Mine (UNC)	-	0.911±0.063	0.862±0.131	-	-	
	-	0.620±0.026	0.509±0.052	-	-	
	-	0.486–0.490 (5 samples)	0.495–0.531	-	-	
N.E. Church Rock Mine (KM)	-	0.110±0.29	0.0474±0.4820	-	-	
CRETACEOUS DAKOTA SANDSTONE						
Church Rock Mine	-	0.834±0.421	0.775±0.861	-	-	Ludwig and others (1982)
Hogback No. 3-5	-	67,000–68,000 yrs.	100,000–102,000 yrs.	-	160,000±30,000 yrs.	Ludwig and others (1977)

UNC - United Nuclear Corporation

KM - Kerr McGee Corporation

older than mineralization in the Morrison Formation.

The Morrison Formation was deposited 135-150 m.y. ago (Berglof, 1969). Rb/Sr isochron age dates of clay minerals in barren sandstones of 142 ± 14 m.y. and 139 ± 26 m.y. are consistent with this time period (Brookins, 1975, 1980; Lee and Brookins, 1978, 1980). One problem with these dates is that the older Westwater Canyon Member in the Ambrosia Lake subdistrict is 132 ± 26 m.y., whereas the age of the younger Jackpile sandstone in the Laguna subdistrict is 142 ± 14 m.y. The reasons for this discrepancy are unclear, but may be related to the disturbance of the Rb/Sr system in a manner such as differing burial depths or ion exchange (Brookins, 1980). Their error intervals do overlap. Additional dating is required to resolve this inconsistency.

Rb/Sr isochron dates of primary tabular ore from the Smith Lake and Ambrosia Lake subdistricts are 139 ± 13 m.y., during or just after deposition of the Westwater Canyon and lower Brushy Basin Members (Brookins, 1975, 1980; Lee and Brookins, 1978, 1980). The Rb/Sr isochron date of primary tabular ore from the Laguna subdistrict is 113 ± 7 m.y., considerably less than the Jackpile sandstone and less than ore at Ambrosia and Smith Lakes subdistricts. This younger age from the Laguna subdistrict suggests either that the Jackpile ore is younger than the Westwater Canyon and lower Brushy Basin ore, or that the Jackpile ore has been oxidized and partially redistributed in early Cretaceous times (S. S. Adams and others, 1978; S. S. Adams and Saucier, 1981). The available information is too inconclusive to refute either arguement.

The Cretaceous Dakota Sandstone was deposited 90 to 94 m.y. ago (Brookins, 1980; Obradovich and Cobbin, 1975), suggesting that primary tabular ore in all three subdistricts occurred prior to deposition of the Dakota Sandstone. This is consistent with field observations in several areas at Poison Canyon and Laguna subdistricts, where ore pods appear to be truncated by local intraformational erosional surfaces (Squyres, 1980; Nash and Kerr, 1966).

Pb/U apparent age dates of ore in the Grants district are generally younger than Rb/Sr isochron dates. The Pb/U dates are discordant due to (1) lead loss, (2) ore redistribution, (3) addition of uranium, and (4) loss of radiometric daughters. However, nearly concordant age dates and an average of Pb/U apparent age dates (Dooley and others, 1966b) confirm that primary tabular mineralization occurred 90 to 100 m.y. ago, prior to deposition of the Cretaceous Dakota Sandstone. Furthermore, the Pb/U apparent age dates from the Jackpile-Paguate and Woodrow mines indicate that mineralization of these two deposits (one a sandstone deposit, the other a breccia-pipe deposit) is of the same age.

Several authors have suggested that a Late Jurassic-Early Cretaceous period of redistribution may have occurred (R. J. Peterson, 1980; Sanford, 1982; Galloway, 1980). The Pb/U dates may be indicative of such a period of oxidizing, dissolution, and redistribution. Only additional studies will resolve these problems.

Post-Cretaceous ages (Table 5) can be grouped into several intervals. Only one date, a Pb/U apparent age of 68.7 $\pm$ 0.5

m.y., falls within the age of mineralization that possibly could have occurred during Laramide times. The association of Laramide faults with uranium mineralization led Finch (1967) to interpret some stack ore as being Laramide in age. Any Laramide mineralization should have age dates within the 60-70 m.y. range (Brookins, 1980). However, Ludwig and others (1982) postulates that this particular Pb/U date is a result of contamination of primary tabular ore by younger redistribution events. Dooley and others (1966b) report the average age of post-fault ore to be 10 m.y. to Recent. Dating of mineralization associated with Laramide fault-zones is required before any mineralization can be attributed to Laramide times.

Post-Laramide mineralization is suggested by field observations throughout the Grants district (Saucier, 1980; D. S. Clark, 1980). The Rb/Sr isochron date of 30 $\pm$ 90 m.y. (Brookins, 1980) would be representative of such mineralization, especially if individual Rb/Sr determinations were from different periods of mineralization. Pb/U apparent age dates can be divided into five groups at about 13-15 m.y., 6-10 m.y., 0.9-2 m.y., 500,000 yrs., and 50,000-160,000 yrs. (Table 5). These five groupings suggest at least five different redistribution events in the Grants district. The same cyclic events could have affected the Todilto Limestone (Table 5).

Available age determinations suggest that three redistribution events affected the Ambrosia Lake and Smith Lake subdistricts during the 13-15 m.y., 6-10 m.y., and 0.9-2 m.y. periods. Three younger redistribution events appear to have affected the Church Rock subdistrict during the 0.9-2 m.y., 500,000 yrs., and 50,000-160,000 yrs. Younger redistribution events up until recent times also appears to have affected the Nose Rock deposits (D. S. Clark, 1980), although no age dates from Nose Rock are available. These observations are preliminary and are subject to change when additional age determinations become available.

Laguna subdistrict

The Laguna subdistrict forms the eastern end of the Grants uranium district in Cibola and Bernalillo Counties (Figs. 4, 6, 7) and accounts for approximately 29% of the total pre-1970 uranium production in New Mexico (McLemore, 1982c). In the Laguna subdistrict, 45 deposits or occurrences are found in the Morrison Formation (Appendix 1). Of these, 37 are in the Brushy Basin Member (including 31 in the Jackpile sandstone), 5 in the Westwater Canyon Member, and 3 in the Recapture Member (Fig. 6, Appendix 1). In addition, uranium deposits occur in breccia-pipes and the Todilto Limestone in this subdistrict; these deposits are discussed separately. Five mines or mine complexes have produced during 1952 to 1982 (Appendix 3); none of the operations are currently active. The JJ #1 and St. Anthony mines are on stand-by status.

The first discovery in this area was in 1951 by aerial reconnaissance at the Jackpile-Paguate mine. This mine is now the largest uranium mine in the world. Over 80 million lbs (36 million kg) of U_3O_8 has been produced in thirty years of operation (Hoppe, 1978), and remaining reserves are substantial.

The Jackpile-Paguate mine consists of four coalescing open pits, numerous adits, and one decline (Fig. 16). The JJ #1 and St. Anthony mines are northeast of the Jackpile-Paguate mine (Fig. 12). The mineralization at the JJ #1 is mined through a 672-ft (205-m) shaft. The St. Anthony mine was first operated in 1953 as an open cut and a 298-ft (91-m)shaft. United Nuclear acquired the property in the 1960's, and sank a 357-ft (109-m) shaft and excavated two open pits in 1977 (Fig. 12). In addition to these ore bodies, one deposit and several mineralized drill holes occur in the Jackpile sandstone north of the JJ #1 mine (Fig. 12). However, less than 3% of the Jackpile sandstone is mineralized (Moench and Schlee, 1967).

The Morrison Formation in the Laguna subdistrict is about as thick as in the Ambrosia Lake subdistrict, approximately 600-700 ft (183-213 m) thick. However, the Brushy Basin Member is significantly thicker in the Laguna subdistrict than at Ambrosia Lake, whereas the Westwater Canyon and Recapture Members are thinner to absent. Most of the economic deposits occur in the Jackpile sandstone of the Brushy Basin Member, although uranium has been produced from the Todilto Limestone and Recapture Member (Chavez Lease).

Uranium mineralization in the Laguna subdistrict is primary-tabular and is associated with organic material. Fossil logs are common in the Jackpile sandstone, but are rarely mineralized. Mineralization in the Jackpile sandstone occurs as (1) multiple lenses of grain coatings, (2) irregular and diffuse masses of ore, and (3) discontinuous, thin, mineralized coal-like lenses. The coal-like seams or lenses have been reported elsewhere in the

Morrison Formation, but are not mineralized except in the JJ #1 and St. Anthony ore deposits. Some of the carbonaceous material and perhaps some of the uranium mineralization were deposited as discrete detrital grains and as concentrations along bedding and crossbedding planes (Jacobsen, 1980; Baird and others, 1980). However, much of the carbonaceous material and associated mineralization occur as replacements of grains, pore fillings, and concentrations around clay galls and at sandstone-shale interfaces (Beck and others, 1980; Moench and Schlee, 1967). This later form of mineralization exhibits no relationship to cross-stratification or to lithologic units, as it cuts across these features. Average ore grades may range as high as 0.9% U_3O_8.

The ore bodies in the Laguna subdistrict tend to align in a northeast-trending belt subparallel to the axis of the Jackpile sandstone (Fig. 12). Although, trace amounts of Mo and Se and minor amounts of V occur in these deposits, the quantities of these associated elements are far less than concentrations in primary tabular deposits in Ambrosia Lake and Smith Lake subdistrict. Dating of mineralization in the Jackpile sandstone suggests that it is younger than the Jackpile sandstone and the primary tabular mineralization in Ambrosia Lake and Smith Lake subdistricts (Table 5). This conflicts with observations of detrital uranium mineralization (Jacobsen, 1980; Baird and others, 1980), however, the age date is consistent with observations and interpretations of mineralization occurring prior to deposition of the Cretaceous Dakota Sandstone (Nash and

Kerr, 1966; Moench and Schlee, 1967). Additional studies are needed to resolve some of the conflicting evidence.

Additional uranium occurrences in the Brushy Basin, Westwater Canyon, and Recapture Members are minor, although the Chavez Lease produced from the Recapture Member in 1955. Production from the Chavez Lease amounted to 821 lbs (372 kg) of U_3O_8 at an average grade of 0.21%. Although the majority of the potential resources in the Laguna area occur in the Jackpile sandstone, some are thought to occur in the Recapture Member and the Todilto Limestone (U.S. Department of Energy, 1980).

Marquez-Bernabe Montaño area

The Marquez-Bernabe Montaño area lies north of the Laguna subdistrict, in McKinley, Cibola, and Sandoval Counties (Fig. 4). Only one mine has produced uranium ore from this area, although several large deposits are found in the Westwater Canyon Member (Fig. 6). Kerr McGee produced ore from the Westwater Canyon Member at the Rio Puerco mine in 1979 and 1980. Exxon located several shallow, low-grade ore bodies in the San Antonio Valley area (S. C. Moore and Lavery, 1980). Kerr McGee and Bokum discovered separate ore bodies in the Marquez area. Kerr McGee drilled in the area in 1982, whereas Bokum suspended shaft-sinking and construction of a mill due to financial difficulties. Conoco also located ore bodies on the Laguna Indian Reservation, at Bernabe Montaño (Kozusko and Saucier, 1980).

The Westwater Canyon Member is approximately 200 to 300 ft (61 to 91 m) thick in the Marquez-Bernabe Montaño area. The depth of mineralization is about 800 ft (244 m) at the Rio Puerco mine, about 900-1,000 ft (244-305 m) at San Antonio Valley, about 2,100 ft (640 m) at Marquez, and about 1,000-2,500 ft (305-732 m) at Bernabe Montaño. Preliminary studies indicate that most of the mineralization is primary tabular ore and occurs in multiple horizons (S. C. Moore and Lavery, 1980; B. A. Livingston, Jr., 1980; Kozusko and Saucier, 1980).

At Marquez, ore is controlled by shale breaks, high permeability, and recurrence of meandering streams. Where the shale beds are absent, uranium mineralization is dispersed throughout the sandstone and is subeconomic. Mineralized sandstones tend to be permeable; however, excessively permeable sandstones allow mineralization to be redistributed elsewhere. Mudstone pebbles restrict the permeability and concentrate uranium mineralization. Uranium mineralization appears to be restricted to meandering channels within the dominantly braided-stream complex (B. A. Livingston, Jr., 1980). Actual development and mining of these deposits will add to our knowledge of mineralization in this area.

A few minor occurrences are found in the Jackpile sandstone and the Brushy Basin Member near the Rio Puerco mine (Fig. 6). Two minor occurrences are found in Cretaceous coal beds south of the Bernabe Montaño area (Fig. 1). Two beach-placer sandstone deposits occur in the Bernabe Montaño area and will be discussed separately.

Ambrosia Lake Subdistrict

Over 200 uranium occurrences are found in the Ambrosia Lake subdistrict in the Todilto Limestone, Morrison Formation and

Cretaceous sediments (Figs. 7, 8, 11; Appendix 1). Over half of these occurrences are in the Morrison Formation, mostly in the Westwater Canyon member and the Poison Canyon sandstone. More than 50 of these occurrences have produced uranium since the initial sandstone discovery in Poison Canyon in 1951 (Appendix 3). The Blue Peak mine was the first underground uranium mine in the Grants district. The Ambrosia Lake-Mt. Taylor trend (Fig. 11) is the largest mineralized area in the Grants district and accounts for substantial portion of the reserves and potential resources in New Mexico (McLemore, 1981; U.S. Department of Energy, 1980). Production from this district has exceeded 77,000 tons (69,500 metric tons) of U_3O_8 (Holen and Fitch, 1982). One of these deposits, Gulf's Mt. Taylor, contains more than 100 million pounds (45,000 metric tons) of U_3O_8 (Cheney, 1981; Jackson, 1977). More than 326,000 tons (296,000 metric tons) of U_3O_8 at an average grade of 0.10% U_3O_8 is estimated to occur in the Ambrosia Lake-Mt. Taylor trend (Holen and Fitch, 1982).

The Morrison Formation in this area is approximately 600-700 ft (183-213 m) thick, about the same thickness as in the Laguna subdistrict. However, the Westwater Canyon and the Recapture Members are thicker in the Ambrosia Lake area than at Laguna. The Jackpile sandstone is absent in the Ambrosia Lake area. The Westwater Canyon Member and the Poison Canyon sandstone are the principle sandstone hosts for mineralization in the Ambrosia Lake subdistrict. The Westwater Canyon Member consists of three or more thick-bedded, coarse-grained, arkosic sandstones separated by thin beds of shale and siltstone (Hilpert, 1969). The Poison Canyon sandstone is the basal sandstone of the Brushy Basin

Member and consists of arkosic sandstone similar in appearance and composition to the Westwater Canyon sandstones. Mineralization ranges in depth from the surface at Poison Canyon to 700 to 900 feet (213-274 meters) at Ambrosia Lake, to 3,300 feet (1,060 meters) at Mt. Taylor.

Uranium mineralization occurs as primary-tabular and redistributed ore bodies. Primary-tabular ore bodies are typical of the occurrences elsewhere in the district. This mineralization is not directly controlled by faults, fractures, or folds; however, they tend to subparallel depositional features such as channel configuration, cross-stratification, and intraformational disconformities. These ore deposits occur as groups of lenses or pods and may split and occupy several stratigraphic horizons. The ore trends are well developed in the Ambrosia Lake-Mt. Taylor area (Fig. 11).

Redistributed ore bodies are geochemical cell-controlled and in places localized along fractures and faults. Multiple horizons of "stacked" ore along Laramide faults may attain a thickness of over 100 ft (30 m). These ore bodies are closely associated with primary tabular ore bodies and grade into them (Hilpert, 1969). Fracture-controlled redistributed-ore occurs in the western portion of Ambrosia Lake (Granger and others, 1961) and at Poison Canyon mine (Tessendorf, 1980). At the Poison Canyon mine, remnants of ore around fossil logs in limonitic sandstones occurs updip from fracture-controlled ore (Tossendorf, 1980).

Geochemical cell-controlled, redistributed ore is found in the Ambrosia Lake area, but may be difficult to distinguish from primary tabular ore. Alteration patterns suggest redistribution and remobilization of primary tabular ore at the Sandstone mine (Foster, J. F. and Quintanar, 1980). Small roll-type deposits occur at the Johnny M mine (Falkowski, 1980a, b). Relicit or remnant mineralization occurs in section 28, T. 14 N., R. 10 W. (D. A. Smith, and Peterson, 1980) section 23, T. 14 N., R. 10 W. (Harlen Holen, pers. commun., 1983) and at Poison Canyon mine (Tessendorf, 1980).

The Johnny M mine is one of several deposits in the Grants uranium district where ore occurs in both the Poison Canyon sandstone and the Westwater Canyon Member (Falkowski, 1980a, b). Primary-tabular and roll-type ore occur in the Westwater Canyon Member where organic debris is abundant. Uranium mineralization commonly occurs around fossil logs and debris accumulations and shows the direction of the groundwater flow (Falkowski, 1980a, b). Mineralization in the overlying Poison Canyon sandstone is more massive and lower in grade than ore in the Westwater Canyon Member. Organic debris and fossil logs are not common in the Poison Canyon sandstone, and no roll-type deposits have been delineated.

The most recent exploration activity in the Ambrosia Lake subdistrict is at La Jara Mesa (12N.9W.12.300, Appendix 1) where Midas has discovered a small- to medium-sized ore body in the Poison Canyon sandstone at about 600 ft (183 m) depth. This ore body is probably an extension of the Taffy mine (12N.9W.11.334, Appendix 1). Homestake is studyng the feasibility of mining this ore body. Recent reports indicate there is a potential for 10 million lbs (4.5 million kg) of uranium on the property (New Mexico Uranium Newsletter, August 1983).

Uranium occurrences are found in the basal Recapture Member (Appendix 1); however, none of these deposits have yielded any ore. The extent of these occurrences is not known, although Kerndamex found good, high-grade ore northwest of San Mateo (Harlen Holen, pers. commun., 1983). Small to medium ore deposits are found in the Todilto Limestone, as previously discussed. Although, exact quantities of reserves in the Morrison Formation and Todilto Limestone in this subdistrict are not available due to proprietary information, they are substantial and mining will continue, providing economic conditions improve. The majority of the potential uranium resources are estimated to occur in the Westwater Canyon Member, but potential resources are also thought to occur in the Recapture Member, the Todilto Limestone, and Cretaceous Dakota Sandstone (U.S. Department of Energy, 1980).

Smith Lake subdistrict

The Smith Lake subdistrict is southwest of Crownpoint and north of Thoreau in McKinley County (Fig. 4). Eight mines in this area have produced ore in the past; they are Mariano Lake, Black Jack No. 2, Mac No. 2, Ruby No. 1, 2, and 3, and Black Jack No. 1 (Fig. 13). Two additional ore bodies occur in the area, Phillip's section 20 and Western Nuclear's Ruby No. 4 (Fig. 13). Development of the Ruby No. 4 ore body has begun and production will start upon reopening of the Ruby No. 3 decline.

Only one mine, the Black Jack No. 1, and several mineralized drill holes in sections 11, 13, and 14, R. 15 N., R. 13 W., occur in the Westwater Canyon Member. The remaining seven mines and two ore bodies, and miscellaneous mineralized drill holes all are in the Brushy Basin member and are aligned in a northwest-southeast trend (Fig. 13). In addition, three mineralized drill holes in the Morrison Formation have been discovered northwest of the Mariano Lake mine (Appendix 1); however, no other information is available (Neil Fishman, written commun., 2/83).

At least two periods of mineralization occurred at the Black Jack No. 1 mine in the Westwater Canyon Member. Two horizons of primary-tabular ore are restricted to well cemented sandstones in the northern and western portions of the mine (MacRae, 1963). Younger, redistributed, fault-controlled ore is associated with fractured and permeable sandstones separated by numerous shale breaks in the eastern portion of the mine. More than seven horizons were deposited along the major faults. Nearby mineralized drill holes may represent remnant or relict ore pods.

Ore deposits in the overlying Brushy Basin member are aligned in a northwest-southeast trend (fig. 13) and occurs in the two lowermost sandstone units. The Brushy Basin member in this area ranges from 80-180 feet (24 to 55 meters) thick and sandstones make up almost half of the unit. The two mineralized sandstones are separated by ten feet (3 meters) of shale and may be stratigraphically equivalent to the Poison Canyon sandstone in the Ambrosia Lake subdistrict.

Ore deposits in the overlying Brushy Basin Member are aligned in a northwest-southeast trend (Fig. 13) and occur in the two lowermost sandstone units. The Brushy Basin Member in this area ranges from 80 to 180 ft (24 to 55 m) in thickness and sandstones make up almost a half of the unit. The two mineralized sandstones are separated by 10-20 ft (3-6 m) of shale and may be stratigraphically equivalent to the Poison Canyon sandstone in the Ambrosia Lake subdistrict.

Uranium mineralization in the lowermost Brushy Basin sandstone has features typical of classical roll-type deposits (Mathews and others, 1979). A well defined "C" geometry and characteristic pyrite-limonitic-hematitic alteration pattern are found at the Ruby mines (Ristorcelli, 1980; Keith Rosvold, Western Nuclear, written commun., 1981); however, variations of the roll-type deposit are common. The Mariano Lake ore body occurs on the reduced side of the redox interface and was classified a roll-type deposit (Jenkins and Cunningham, 1981; Place and others, 1980; Sachdev, 1980). However, petrographic, geochemical and isotopic studies indicate that at least part of the Mariano Lake ore body may be primary-tabular (Fishman and Reynolds, 1980). Fission track and Rb/Sr studies at Mariano Lake also suggest at least two periods of mineralization (Lee and Brookins, 1978; Rosenberg and Hooper, 1982). A redox boundary exists at the Black Jack No. 2 and Mac No. 1 mines, but no well defined geometry or alteration patterns were observed (Hoskins, 1963).

A remnant ore body occurs in the lowest sandstone at the South Pod ore body (Western Nuclear Ruby No. 3 mine), where primary tabular mineralization is surrounded by oxidized sandstone. The mineralized sandstons are well cemented with calcite, which reduces permeability. Thick adjacent overbank mudstones form a bottleneck near the ore body and may have restricted oxidizing fluids from redistributing the mineralization (Fig. 17). Other remnant ore bodies may occur in the Smith Lake area, but are difficult to locate.

Mineralization in the middle sandstone occurs at Mac No. 2 and Ruby No. 3 mines. The ore at the Ruby No. 3 mine is primary tabular and occurs downdip from a redox front. Small ore pods occur in front of and at the redox interface, but does not have the typical geometry of a roll-type deposit (Ristorcelli, 1980). It is possible that this ore is primary tabular, similar to ore at Mariano Lake mine (Fishman and Reynolds, 1982). Well cemented sandstones and the nature of the uranium-humate complexing helped in preserving these deposits from redistribution.

The Mariano Lake anticline, north of the Smith Lake mines (Fishman and Reynolds, 1982), may have some structural control and hydrologi effect on the Smith Lake deposits (Place, 1980; Fishman and Reynolds, 1982). The Mariano Lake anticline may have impeded ground-water flow in the vicinity of the Mariano Lake and Ruby No. 1 deposits, which helped to preserve these ore bodies (Fishman and Reynolds, 1982).

Additional research is needed in the Smith Lake area to adequately classify these deposits. Locally, only one major redox event appears to have affected the ore bodies; but did not completely redistribute the mineralization. Elsewhere, additional migration of uranium mineralization is indicated from age dating by Brookins (1980), Lee and Brookins (1978), and

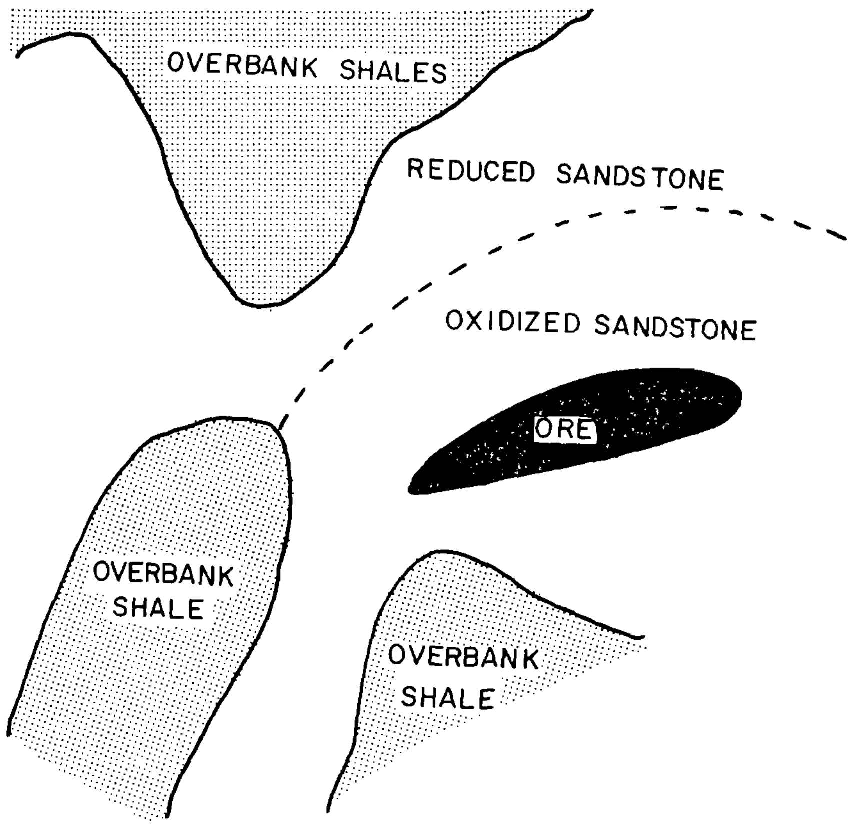


FIGURE 17-SKETCH MAP OF A RELICT OR REMNANT ORE BODY IN THE BRUSHY BASIN MEMBER IN THE SMITH LAKE SUBDISTRICT, NEW MEXICO (MODIFIED FROM K. S. ROSVOLD, UNPUBLISHED REPORT, 1981).

Rosenberg and Hooper (1982). Age dates by Brookins (1980) indicate that primary-tabular mineralization in the Smith Lake and Ambrosia Lake subdistricts are of the same age. This relationship needs to be studied in more detail.

Additional minor occurrences are found in the Recapture Member in the Smith Lake area as well as in the Westwater Canyon and Brushy Basin Members east and west of the mineralized Smith Lake trend (Figs. 1, 8, 9; Appendix 1). The significance of these occurrences is unknown. Uranium resources are thought to occur in the Brushy Basin Member, Westwater Canyon Member, Recapture Member, Todilto Limestone, and Cretaceous Dakota Sandstone (U.S. Department of Energy, 1980).

Church Rock subdistrict

The Church Rock subdistrict (or Gallup subdistrict) forms the west end of the Grants uranium district in McKinley County (Fig. 4) and contains about 50 uranium occurrences in the Morrison Formation (Appendix 1, Figs. 8, 9). Most of these occurrences are found in the Westwater Canyon Member, although uranium mineralization also occurs in the Brushy Basin Member and the Cretaceous Dakota Sandtone at six localities. Uranium mineralization in this area was discovered in the early 1960's; however, recent extensions of the district northward and eastward in the Crownpoint area have greatly increased reserves and potential resources. Two distinctive trends occur in the subdistrict; one at the Gallup area where mineralization occurs in the Westwater Canyon and Brushy Basin Members and the Dakota Sandstone, and the second trend at Crownpoint where mineralization occurs in the Westwater Canyon member. It is estimated that reserves at the Gallup trend exceed 100 million lbs (45 million kg) of U_3O_8 (Holen and Finch, 1982). Reserves are confidential for the large deposits owned by Mobil at Crownpoint. Conoco's Section 29 deposit contains 10 million lbs (3 million kg) of U_3O_8 (Wentworth and others, 1980). Additional deposits between 5 and 20 million lbs (1-6 million kg) of U_3O_8 occur at Dalton Pass, Narrow Canyon, and Canyon Prospects (Perkins, 1979); the reliability of these reserve estimates is unknown. Potential uranium resources also occur in the Westwater Canyon and Recapture members (U.S. Department of Energy, 1980).

In the Gallup area, (Figs. 8, 9) redistributed ore bodies are common. R. J. Peterson (1980) describes a pre-Dakota geochemical cell-controlled ore deposit in section 13, T. 16 N., R. 17 W.; although primary tabular mineralization may also be preserved. Elsewhere, ore deposits near the surface are oxidized. Redistributed ore occurs at the Church Rock and Northeast Church Rock mines.

The Church Rock mine was operated during the early 1960's and reopened in 1976 by United Nuclear Corp. Ore occurs in multiple horizons in the Westwater Canyon and Brushy Basin Members and the Cretaceous Dakota Sandstone, and is below the water table. Most of the mineralization is controlled by a steeply dipping fracture system that trends northeastward (Hilpert, 1969). Mineralization in the Dakota Sandstone occurs along the fracture system in the Westwater Canyon Member, and these redistributed ore bodies grade into thin, uneconomic blankets of primary tabular mineralization.

At United Nuclear's Northeast Church Rock mine further north (Appendix 1, Figs. 8, 9), redistributed mineralization is also associated with a northeast-trending fault system. Two mineralized horizons occur in the Westwater Canyon Member and average about 0.20% U_3O_8. Over 15 million lbs (7 million) kg) is estimated to occur at this deposit (Hilpert, 1969).

At Kerr McGee's Northeast Church Rock 1 and Church Rock 1-East mines, mineralization occurs in five sandstones of the Westwater Canyon Member at 1,500 to 2,000 feet (543-610 m) deep. These east-west trending ore deposits are 3-10 ft (1-3 m) thick and average 0.19% U_3O_8 in grade. Primary tabular and redistributed ore bodies are present. Primary tabular ore forms the bulk of the deposit in the middle sandstones of the Westwater Canyon Member, and may have been reworked by early geochemical-cell processes. Typical geochemical-cell controlled roll-front deposits are well developed in the upper sandstone of the Westwater Canyon Member. Fracture-controlled mineralization occurs in the lower sandstones of the Westwater Member and is similar to fracture-controlled deposits in the Ambrosia Lake area. Geochemically, the primary tabular ore deposits are different from primary tabular ore deposits elsewhere in the Grants uranium district. The Northeast Church Rock deposits are lower in organic C, V, and S than primary tabular deposits elsewhere (Fishman and Reynolds, 1983). Furthermore, they appear to be younger in age than deposits in the Smith Lake and Ambrosia Lake areas (Ludwig and others, 1982).

Uranium mineralization at Crownpoint occurs in the 260 ft

(79 m) thick Westwater Canyon member at depths of approximately 2,000 ft (610 m). Up to four mineralized horizons occur at Conoco's deposits in the upper Westwater Canyon Member (Wentworth and others, 1980). Ore appears to parallel sedimentary trends, although thick adjacent mudstones may have contributed to localizing the humates and uranium (Wentworth and others, 1980). These ore deposits are enriched in Mo, V, and Se, and are typical of primary tabular mineralization elsewhere in the Grants district, although redistributed ore may occur locally. Vogt and others (1982) describe the occurrence of uraninite mineralization that is not associated with abundant humic material or coffinite. This may be representative of redistributed ore.

Conoco-WMC (Wyoming Mineral Corp.) recently suspended shaft sinking at its Crowpoint property and now the property is controlled by WMC. Mobil succeeded in producing uranium by in situ leaching in Texas, and the small and isolated ore bodies in the Crownpoint area prompted Mobil to attempt in situ leaching at Crownpoint. Mobil's pilot in situ leaching plant was successful, and Mobil plans continue in situ leaching of their deposits. A slurry containing the yellowcake (U_3O_8 concentrate) is shipped to Texas for processing.

Nose Rock area

The Nose Rock area forms the northern extension of the Grants uranium district northeast of Crownpoint, in north-central McKinley County (Fig. 4). Although this area has not been completely explored, over 25 million lbs (11 million kg) of U_3O8 in reserves is estimated by Phillips Petroleum Company (D. S.

Clark, 1980). Uranium mineralization occurs in the Westwater Canyon Member at 3,000 to 4,500 ft (914-1,372 m). A southeast migrating redox front has concentrated uranium mineralization in unoxidized sandstones in the Nose Rock area, contrary to the northward-migrating front in the Ambrosia Lake and Smith Lake subdistricts. This primary geochemical-cell controlled ore may be older than primary ore at Ambrosia Lake and differs from redistributed ore (D. S. Clark, 1980). The presence of several roll-type ore bodies in the Nose Rock area may suggest that several redox events occured. Shaft sinking at Nose Rock was suspended in 1981 before any conclusive evidence regarding the nature and genesis of these ore deposits could be obtained.

Chaco Canyon area

The Chaco Canyon area is located north of the Church Rock subdistrict, southeast of the Chaco Canyon National Monument in McKinley and San Juan Counties (Fig. 4). In July through November, 1978, Bendix Field Engineering Corp., contractor for the U.S. Department of Energy, drilled 15 holes 4,200 to 5,200 ft (1,280-1,580 m) deep to test the uranium potential of the Morrison Formation in deeper portions of the San Juan Basin (Hicks and others, 1980; Bendix Field Engineering Corp., 1979).

Five drill holes penetrated nine mineralized zones in both the Westwater Canyon and lower Brushy Basin Members. The zones contain from 0.015 to 0.125% eU_3O_8 (radiometric equivalent U_3O_8). Mineralization occurs at the contacts between altered arkosic sandstones and mudstones. The lithology and depositional environments of the sandstones in the Chaco Canyon area are similar to sandstones elsewhere in the Grants uranium district, but the uranium mineralization is thinner and lower grade than in the Grants uranium district. The uranium mineralization in Chaco Canyon also contains less organic carbon than primary tabular mineralization elsewhere in the Grants uranium district (Lease, 1979; Brookins, 1979; Hicks and others, 1980).

The U.S. Department of Energy (1980) has estimated potential resources in the area (McLemore, 1981). The presence of the uranium mineralization in the Westwater Canyon and Brushy Basin Members does indicate a potential for uranium deposits in the deeper portions of the San Juan Basin. The economic feasibility of production remains to be proven.

Reflections and synthesis of Morrison mineralization in the Grants uranium district

Although the uranium deposits in the Grants uranium district have been studied for over thirty years and have received more attention than most mineral deposits, geologists cannot agree on the origin and genesis of the ore bodies. The following comments and observations on this problem are in order:

1) Three types of mineralization are found in the Grants uranium district; they are (a) primary tabular (trend or prefault), (b) redistributed (stack or fault-controlled and roll-type or geochemical-cell controlled), and (c) remnant or relict primary ore.
2) Mineralization is similar whether in sandstones of the Westwater Canyon Member, Brushy Basin Member, Poison Canyon sandstone, or Jackpile sandstone, although local differences do occur.

3) The nature of the organic material is still unclear, although a humic affinity appears most likely (Squyres, 1980; Leventhal, 1980; Granger, 1968). Petrographic relationships, chemistry, and uranium distribution imply that uranium was introduced into the sediments after the organic material was emplaced, but before sediment compaction (Webster, 1983).

4) Primary tabular ore bodies are typically enriched in Mo, V, and Se. However, Mo and V are generally absent or in low concentrations in redistributed ore bodies.

5) Bleached sandstones and altered feldspars and magnetite are associated with mineralization.

6) The importance of composition of the host sandstones, geometry of the host sandstones, clay mineralogy, or ground-water flow is unclear at the present time.

7) Depositional environments of host sandstones may have locally controlled humate and uranium concentration. However, any conclusive associations between mineralization and depositional environments have not been demonstrated.

8) Most of the primary uranium mineralization exhibits little or no relationship to tectonic structures. However, pre-Cretaceous structures influenced the deposition of host sandstones and ground-water flow and therefore, may have indirectly influenced primary tabular mineralization. After deposition of the host sandstones, regional strucures may have influenced ground-water flow and, in turn, redistribution and mobilization of uranium mineralization.

9) Mobilization and redistribution of primary tabular ore

occurred periodically and produced redistributed ore bodies of different ages. Some primary tabular ore may hae been originally deposited by geochemical processes (roll-type). Subsequent geochemical events redistributed this ore.

10) Numerous sources exist for the uranium and associated elements. L. T. Silver, (1977) found zircons in granitic basement rocks to be anomalously high in uranium and suggested these rocks as a potential source. The alteration of acid volcanic detrital fragments within the host sandstones (D. C. Fitch, 1980; Falkowski, 1980a, b) could release uranium into the ground water system. Alteration of volcanic ash units in the source terrain also could release uranium (S. S. Adams, and Saucier, 1981). A regional uraniferous source terrain appears to be a likely source for these deposits.

11) Numerous sources exist for the ore-controlling humates. Humates may be derived from (a) buried organic material and logs within the host sandstones (Squyres, 1980; Granger, 1968); (b) adjacent lacustrine mudstones and shales rich in organic material (F. Peterson, and Turner-Peterson, 1980); (c) detrital material (Jacobson, 1980); (d) overlying Dakota Sandstone (Green, 1980; Granger, 1968; Granger and others, 1961); or (e) organic-rich layers deposited on top of the Morrison Formation prior to deposition of the Dakota Sandstone and subsequently eroded (Green, 1980; Granger, 1968).

12) Preservation of the uranium deposits can be attributed to (a) protective overlying cover of impermeable rocks; (b)

many deposits occur below the water table; (c) the resistance of the humate-uranium mineralization complex to oxidation and mobilization; (d) calcite and clay cementation; and (e) local structures (folds).

The mineralization history of the Grants uranium district is complex and depends upon depositional environments, ground-water flow regimes during depositional and post-depositional events and preservation mechanisms. It is beyond the scope of this report to adequately discuss these problems. The few topics discussed above are intended to provide the reader with a basic understanding of the complexity involved in the formation of these unique uranium deposits.

Shiprock District

The Shiprock district is located on the Navajo Reservation in northwestern San Juan County and is subdivided into two subdistricts, the Chuska (or Sanostee) and Carrizo Mountains. The majority of the uranium deposits occur in the Salt Wash and Recapture Members of the Morrison Formation, although some ore was produced also from the Todilto Limestone. Since 1948, over 495,000 lbs (224,000 kg) of uranium have been produced from this district (Table 4). Only one mine, the Enos Johnson mine in the Chuska subdistrict, has been active during recent times. This mine closed in 1982 because of a lack of a market.

The Salt Wash Member is the lowest member of the Morrison Formation in the area (Fig. 10) and consists of fine- to medium-grained sandstones and sandy and silty shales. The Salt Wash is

220 ft (67 m) thick at Oak Creek in the Carrizo Mountains subdistrict and thins to the north due to a Bluff high. At Sanostee (Chuska subdistrict), the Salt Wash is only 50 ft (15 m) thick. Farther southeast, in the Toadlena and Church Rock areas, the Salt Wash is absent (Hilpert, 1969) due to non-deposition.

The Recapture Member overlies the Salt Wash Member and consists of locally conglomeratic sandstones and minor interbeds of siltstone and shale. The Recapture Member is about 500 ft (152 m) thick at Sanostee and thins northward, where it grades into a sandstone-shale sequence.

The Westwater Canyon Member ranges from 140 to 270 ft (43 to 88 m) thick and consists of arkosic to subarkosic sandstones and shales (Hilpert, 1969). The Brushy Basin Member ranges from 150 to 400 ft (46 to 122 m) in thickness and consists primarily of shale with a few arkosic to subarkosic sandstones (Hilpert, 1969; Green and others, 1980d). The sandstones in these members are typical of the mineralized sandstones in the Grants uranium district; however, detrital organic material is absent in the outcrops (Green and others, 1980d). At least one subeconomic ore deposit is known to occur in the Westwater Canyon Member in this district, and there are a few occurrences and radioactive anomalies in Brushy Basin sandstones (Appendix 1; Green and others, 1980d). In addition, similar lithologies, depositional environments, and alteration between the sandstones in the Shiprock district and the Grants district suggest that these sandstones could contain uranium ore bodies (Green and others, 1980d; U.S. Department of Energy, 1980).

Uranium mineralization occurs in the Todilto Limestone; however, only one property produced ore which was below 0.10% U_3O_8 (Appendix 3). Todilto mineralization is spotty and discontinuous, and does not constitute an economic resource in this area (Green and others, 1980d).

Carrizo Mountains subdistrict

The Carrizo Mountains subdistrict forms the northern portion of the Shiprock district in the eastern Carrizo Mountains along the New Mexico and Arizona border (Figs. 1, 18). Much of the district lies in Arizona (Scarborough, 1981). Uranium and vanadium mineralization was discovered in the Salt Wash Member in 1918 by John Wade (Chenoweth and Learned, 1980a). Radium ore was produced from one lease, owned by George O. Williams and Nephi Johnson from 1923 to 1927 (Bureau of Indian Affairs files, 1927). The area remained inactive from 1927 until 1942, when Curran Brothers and Wade, and the Vanadium Corporation of America obtained mining leases for vanadium in Arizona and New Mexico. Subsequently 12 plots or claims were issued to VCA and the entire lease was commonly referred to as the East Reservation Lease (lease No. I-149-IND-5705). Approximate locations of the five plots in New Mexico are shown in Figure 18. Early production from the East Reservation Lease from 1942 to 1946 amounted to 10,216 tons (9,268 metric tons) of ore averaging 2.47% V_2O_5. Much of the uranium left in the mill tailings was reprocessed at Durango, Colorado, for the Manhattan project. The total amount of contained U_3O_8 is estimated to be 44,950 lbs (20,389 kg; W. L. Chenoweth, written commun., 1983).

The AEC was created in 1947 and, as a result of an ore procurement program, VCA began prospecting and mining on their East Reservation Lease for uranium. The first uranium ore shipments were in April 1948. Mining in the Carrizo Mountains ceased in 1968. From 1948 to 1968, 160,772 lbs (72,925 kg) of U_3O_8 were produced from the New Mexico portion of the Carrizo Mountains subdistrict (Table 4).

Uranium and vanadium mineralization in the Carrizo Mountains subdistrict is restricted to the Salt Wash Member. Ore bodies tend to form clusters that are elongated and blanket-like. Unlike uranium deposits in the Grants uranium district, the ore deposits in the Carrizo Mountains subdistrict are high in vanadium and are controlled by paleostream channels (Hilpert, 1969; Chenoweth and Malan, 1973; Huffman and others, 1980). The U:V ratio averages about 1:7 and ranges from 3:2 to 1:13 (Hilpert, 1969). Ore bodies tend to parallel paleostream channels and are associated with organic material derived frmo adjacent sandbar, swamp, and lake deposits. Most ore bodies are small and irregular, and only a few deposits have yielded over 1,000 tons (907 metric tons) of ore (Appendix 3; Hilpert, 1969). It is likely that additional ore deposits may occur in the area (Hilpert, 1969; Scarborough, 1981; U.S. Department of Energy, 1980; Green and others, 1980d), especially downdip of King Tutt mesa (Fig. 18) in a projection of a mineralized paleochannel system (W. L. Chenoweth, personal commun., 1983). Additional ore bodies may also occur on Horse Mesa (Fig. 18).

The source of uranium and vanadium in the Salt Wash Member is not known, but could have been derived from nearby volcanic

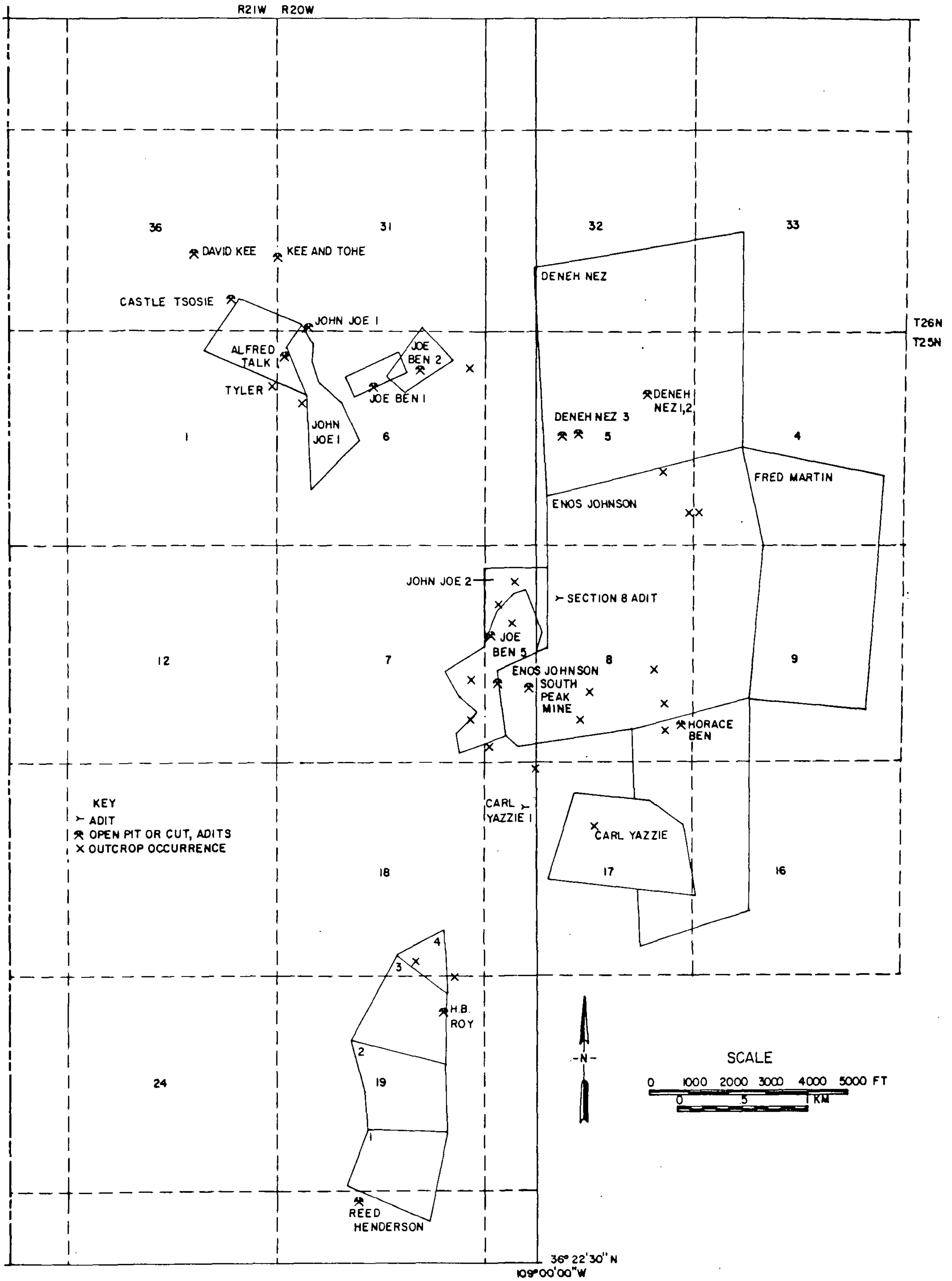


FIGURE 19- URANIUM MINING CLAIMS AND MINES IN THE CHUSKA MOUNTAINS (SANOSTEE) SUBDISTRICT, SHIPROCK DISTRICT, SAN JUAN COUNTY, NEW MEXICO. MODIFIED FROM UNPUBLISHED U.S. ATOMIC ENERGY COMMISSION FILES ([illegible]) AND BLAGBROUGH AND

terrains or volcanic detritus within the Morrison Formation (Thamm and others, 1981; Scarborough, 1981). The time of deposition is not known either, but is presumed to be pre-Laramide in age (Scarborough, 1981).

Chuska Subdistrict

The Chuska or Sanostee subdistrict is in the southern portion of the Shiprock district in the Chuska Mountains (Figs. 1, 19). Uranium and vanadium mineralization was discovered in the Salt Wash and Recapture Members and the Todilto Limestone in the early 1950's and the first ore shipments were made in 1951. From 1951 to 1982, approximately 335,000 lbs (152,000 kg) of U_3O_8 have been produced from 10 properties (Appendix 3; Table 4). The only active mine in recent years in this subdistrict is the Enos Johnson mine, which is the largest producing mine in the Chuska subdistrict and outside the Grants uranium district.

Uranium in the Salt Wash and Recapture Members occurs as grain coatings, cement, and tabular ore bodies in sandstones and is associated with organic material. Mineralized carbonized logs are common. The upper Recapture sandstones contain the largest and richest deposits in the Chuska subdistrict. The U:V ratio averages about 1:2 and ranges from 1:3 to 3:1, similarly to U:V ratios found in the Grants district (Hilpert, 1969). Two types of ore are present. A black ore is associated with organic material and a red ore is associated with hematite. The lack of vanadium and high quantities of clay have hindered the marketing of this ore at mills in Durango and Shiprock. Ore bodies may parallel paleostream channels as in the Carrizo Mountains subdistrict, but nonchannel-controlled peneconcordant ore bodies are common (Green and others, 1980d; Blagbrough and others, 1959). The ore bodies in the Salt Wash are small, ranging from 25 to 50 ft (7 to 15 m) in diameter and up to 2 ft (0.6 m) in thickness (Blagbrough and others, 1959). The ore bodies in the upper Recapture are larger, ranging up to hundreds of feet in diameter and up to 20 ft (6 m) in thickness (Blagbrough and others, 1959). Ore grades in both units average about 0.20% U_3O_8. The source and timing of these deposits are unknown, but probably related to the deposits in the Carrizo Mountains subdistrict. It is likely that additional ore deposits may exist in the Salt Wash and Recapture Members in this area (Blagbrough and others, 1954; Hilpert, 1969; U.S. Department of Energy, 1980; Green and others, 1980d).

Other areas in New Mexico

Several areas outside the Grants uranium district are noted for uranium potential in sandstones and shales in the Morrison Formation. One of the more favorable areas is at the Collins-Warm Springs area in the Nacimiento Mountains, in Sandoval County (Appendix 1). Eleven uranium occurrences are found in the Brushy Basin Member (Appendix 1); one of them, the Collins, produced 989 lbs (449 kg) of U_3O_8 that averaged 0.12% U_3O_8 (Appendix 3). At least three occurrences are found in the Westwater Canyon Member, and one occurrence is in the Morrison Formation, undivided (Appendix 1).

The Recapture, Westwater Canyon, and Brushy Basin Members are present in this area and their lithologies are similar to those in the Grants uranium district (Santos, 1975a). The Westwater Canyon Member is about 240 ft (73 m) thick, but may be locally absent. The Brushy Basin Member is 300 to 350 ft (91-107 m) thick and consists of a lower mudstone unit and the overlying Jackpile sandstone (of economic usage).

Uranium mineralization occurs in at least four horizons in the upper Westwater Canyon Member, the lower unit of the Brushy Basin Member, and lower Jackpile Sandstone. Uranium occurs (1) at the contacts between sandstone and green claystone, (2) along bedding planes and fractures in sandstone and underlying siltstone, and (3) as disseminations within homogeneous sandstone (Kittleman and Chenoweth, 1957). The potential for discovering additional uranium deposits in the Brushy Basin Member in this area is good.

Uranium mineralization occurs in the Westwater Canyon Member at Dennison-Bunn claim south of Cuba in Sandoval County (Fig. 1). The Westwater Canyon Member is about 200 ft (61 m) thick and consists of medium- to fine-grained sandstones, siltstones, and shales. The host sandstones are characteristic of low- to moderately low-energy fluvial environments. The channels trend west-southwest (Ridgley, 1980). Uranium occurs at the irregular boundary between oxidized and reduced sandstones throughout the Westwater Canyon Member in this area, and is associated with iron-stained zones and carbonaceous material. This deposit may be a roll-type deposit (Ridgley, 1980) or a remnant or relict ore body, and may be indicative of additional ore deposits in the area. Geochemical and petrologic studies are needed to adequately classify this ore deposit. Potential resources in the Westwater Canyon Member are thought to occur in this area (U.S. Department of Energy, 1980). as 434 tons (344 metric tons) of U_3O_8 at $30 per pound at an average grade of 0.27% U_3O_8 (U.S. Department of Energy, 1980).

Minor uranium occurrences are found throughout the Morrison Formation in the Majors Ranch area, White Mesa district, Rio Puerco Valley, and Nacimiento Mountains in Sandoval County, and in the Chama Basin and Gallina Mountain areas in Rio Arriba County (Appendix 1). Many drill holes in these areas have penetrated mineralization. However, some of these areas are remote and isolated, and only reconnaissance studies, if any, have been completed (Santos, 1975a; Light, 1982; Chenoweth, 1974b; Kittleman, 1957). Additional work in these areas is warranted.

In eastern New Mexico (Mora, Quay, San Miguel, and Harding Counties), the Morrison Formation is divided into three informal members. The basal member consists of red, green, and purple shales separated by red or gray sandstones. The middle member consists of red, green, and purple shales and red sandstones. The upper member consists of gray and buff conglomeratic sandstones and sandstones and interbedded sandy shales (W. I. Finch, 1972). Twelve uranium occurrences are found in the Morrison Formation in eastern New Mexico (Appendix 1), and only one of these, the Polita #2 in Harding County, produced ore which amounted to 2 lbs (0.9 kg) of U_3O_8 at an average grade of 0.15% U_3O_8 (Appendix 3). A shipment of 30 tons (27 metric tons) of mineralized, silicified logs is reported from the Bel Aro mine

(W. I. Finch, 1972), but is not confirmed by AEC production records.

Uranium generally occurs in the basal member or the lower portion of the middle members, although some minor occurrences are found in the upper member as well (Appendix 1). Uranium is associated with woody material, fossil logs and bones, carbonaceous debris, and at sandstone-shale interfaces. Mineralization is low grade and small in extent. It is doubtful that any large Grants-type deposits occur in these sandstones due to (1) lack of abundant humic material, (2) lack of favorable braided-stream sandstones, and (3) discontinuous and thin sandstones.

Sandstone, Shale, and Coal Deposits in other Formations

Uranium in Pennsylvanian and Permian sedimentary rocks

Pennsylvanian and Permian rocks occur throughout the state and consist of numerous formational units (Dane and Bachman, 1965; New Mexico Geological Society, 1982). Less than 100 uranium occurrences are found in sandstones of the Sangre de Cristo (Pennsylvanian-Permian), Abo (Permian), and Cutler (Permian) Formations (Appendix 1). Production from these units amounts to 295 lbs (134 kg) of U_3O_8 from 10 properties in Mora, Rio Arriba, and Sierra Counties (Appendix 3). Minor, isolated uranium occurrences are also found in the Madera (Pennsylvanian) and Yeso (Permian) Formations. The majority of uranium occurrences in Pennsylvanian and Permian rocks are found in (1) eastern New Mexico, (2) the Nacimiento Mountains in Sandoval and Rio Arriba Counties, (3) the Scholle district in Socorro, Torrance, and Valencia Counties, (4) the Zuni Mountains in Cibola County, (5) the Sierra Cuchillo in Sierra County, and (6) the Sacramento Mountains in Otero County. Minor, isolated occurrences are found in Tijeras Canyon in Bernalillo County, Estey district in Lincoln County, Rayo district in Socorro County, and Iron Mountain and Caballo Mountains in Sierra County (Appendix 1).

In eastern New Mexico, uranium occurs in feldspathic to arkosic sandstones of the Sangre de Cristo Formation (Appendix 1). The Sangre de Cristo Formation overlies marine beds of the Madera Formation. The Yeso Formation and San Andres Limestone overlie the Sangre de Cristo Formation (May and others, 1977).

The Sangre de Cristo Formation consists of interbedded red to maroon sandstones, conglomerates, siltstones, and shales deposited in piedmont, lacustrine, and meandering to braided-stream, alluvial fan environments. The maximum thickness is about 5,000 ft (1,524 m; May and others, 1977).

Twelve uranium occurrences are found in the Sangre de Cristo Formation in Colfax, Mora, San Miguel, and Santa Fe Counties (Appendix 1). Uranium and vanadium have been produced from only one property, the LeDeoux Ranch in Mora County, where production amounted to 9 lbs (4 kg) of U_3O_8 at an average grade of 0.04% (Appendix 3). Uranium-vanadium mineralization typically occurs in fluvial sandstones and conglomerates of a braided-stream environment (Appendix 1; May and others, 1977). Copper occurs with uranium-vanadium mineralization at the Coyote district in Mora county (Tschanz and others, 1958). Gamma-log anomalies are interpreted to represent uranium mineralization in subsurface drill holes, as they are found in several drill holes (Appendix 1; May and others, 1977; Reid and others, 1980a). The presence of uranium occurrences, abundant organic material, favorable lithologies and geometry of host rocks, and a uraniferous source in the Precambrian terrain of the Sangre de Cristo Moutains indicate potential for medium-size uranium ore bodies. The U.S. Department of Energy (1980) is of the opinion that potential uranium resources do occur in this area.

Permian stratigraphy in north-central New Mexico is complex (New Mexico Geological Society, 1982) and will not be described in detail here. North of the Nacimiento Mountains, the dominant uranium-bearing unit is the Cutler Formation which consists of approximately 1,500 to 2,500 ft (457 to 762 m) of fluvial sediments. In the Nacimiento Mountains, in Sandoval and Rio Arriba Counties, the Cutler Formation grades into the Abo Formation and the overlying Yeso Formation (L. A. Woodward, Kaufman, and others, 1974). The Abo Formation is lithologically similar to the Cutler Formation and consists of fluvial sandstones separated by thick shales and mudstones. The Yeso Formation consists of a lower eolian(?) sandstone overlain by marginal marine and intertidal, fine-grained, reddish sediments with local evaporites.

Less than a dozen uranium occurrences are found in the Cutler Formation in Rio Arriba County, and the majority of these are in the Coyote area (Appendix 1). Less than 182 lbs (83 kg) of U_3O_8 were produced from three properties in the Coyote area (Appendix 3). One ore shipment from the Red Head #2 averaged 0.16% U_3O_8; however, other shipments averaged 0.10% U_3O_8 or less (Appendix 3). Uranium occurs with organic material in fluvial sandstones in this area. The uranium potential of this area is uncertain, but is presumed to be low.

In the Nacimiento Mountains, over 35 uranium occurrences are known in the Abo Formation (Appendix 1); however, only two properties, both in the Vegitas Cluster area, have yielded 19 lbs (9 kg) of U_3O_8 (Appendix 3). Uranium mineralization typically occurs with copper mineralization and both are associated with organic material in fluvial sandstones, siltstones, and conglomerates. In the Jarosa area mineralized sandstones are partially eroded, leaving mineralized sandstone remnants exposed;

one of these occurrences is at Teakettle Rock (Fig. 20). Uranium contents rarely exceed 0.10% except in Section 12 (T. 21 N., R. 2 E.) and at Deer Creek where uranium concentration is 0.14% U_3O_8 (Appendix 2). In most places, uranium-copper mineralization is sporadic and discontinuous. Organic material is only locally abundant. The potential for discovering high-grade, large-tonnage uranium deposits in this area is poor.

Uranium and copper minerals occur in meandering fluvial sandstones, conglomerates, and siltstones of the Abo Formation in the Scholle district in Torrance, Socorro, and Valencia Counties (Fig. 21). Although no uranium has been produced from this area, about $700 of radium was produced from the Abo Mining Claims (3N.5E.23.111, Appendix 1) in 1916 (U.S. Bureau of Mines files, 1949). Total mineral production from this district amounts to 15,037 tons (13,641 metric tons) of ore yielding 1,122,465 lbs (509,142 kg) of copper; 426 lbs (193 kg) of lead; 8,148 ounces (230,992 grams) of silver; and 10 ounces (282 grams) of gold between 1915 and 1962 (U.S. Bureau of Mines, Mineral Yearbook, 1904-1981). Five selected samples from this district ranged from 0.001% to 0.017% U_3O_8, 0.83 to 14.33% Cu, 0.05 to 3.18 oz/ton (15.6 to 99.4 mg/kg) Ag, and trace amounts of Au (Appendix 1; McLemore, 1982c). Most of the mines and prospects consist of shafts, pits, and short adits (Fig. 21), and the most extensive underground workings are at Copper Girl No. 1 (Fig. 22) and the Abo Mine. Prospecting for uranium took place in the 1950's, after a local prospector discovered a thin seam of 13% U_3O_8 at the Abo Mining Claims (3N.5E.23.111, Appendix 1).

Uranium and copper mineralization occurs as (1)

Figure 20 - Teakettle Rock in the Nacimiento Mountains is a remnant of a resistant fluvial sandstone in the Permian Abo Formation. Disseminated copper and uranium minerals are associated with carbonaceous material that forms banding within the bleached sandstone.

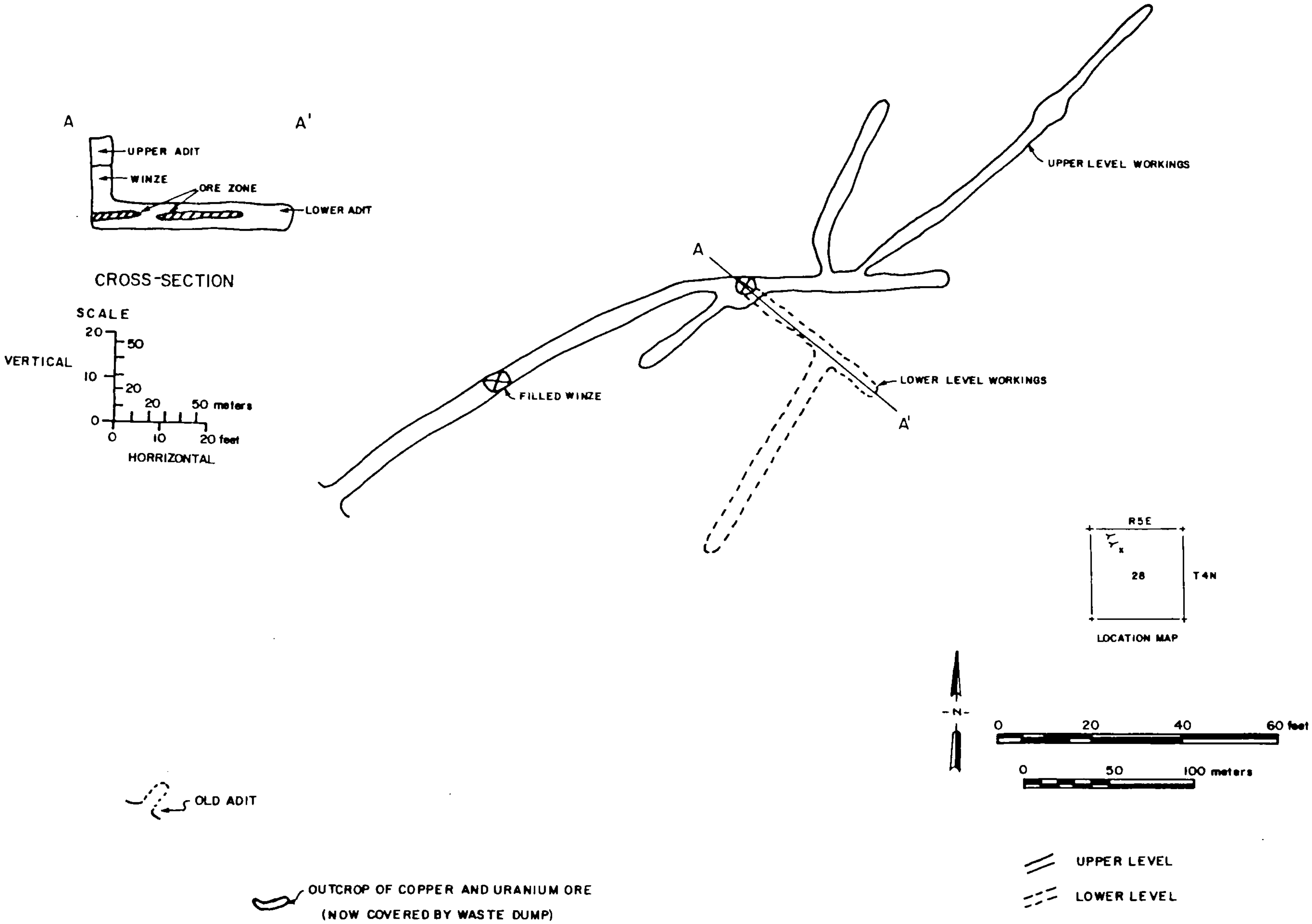


FIGURE 22- PLAN MAP OF THE COPPER GIRL NO.1 MINE, TORRANCE COUNTY, NEW MEXICO.

SIMPLIFED FROM U.S. ATOMIC ENERGY COMMISION MAP (JULY 1955) disseminations within bleached arkosic sandstones, limestone-pebble conglomerates, and gray siltstones; (2) along bedding planes within sandstones and underlying siltstones and shales; and (3) as replacements of wood and organic material. Copper oxides, chalcopyrite, and chalcocite are the dominant copper minerals present; whereas tyuyamunite, metatyuyamunite, carnotite, and uraninite are the dominant uranium minerals present (R. Gibson, 1952; Collins and Nye, 1957b). The uranium-copper mineralization is low grade and discontinuous along the outcrop. Several small but scattered ore bodies were located by subsurface drilling in meandering fluvial sandstones in the vicinity of the Abo Mining Claims. However, none of these ore economic bodies approached economic grades (Collins and Nye, 1957b). Anomalously high uranium and copper concentrations occur in water and stream-sediment samples from the immediate vicinity of the mineralized area, but only weak anomalies occur downdip (Pierson and others, 1981; Planner, 1980). This suggests that only small, scattered, low-grade ore bodies occur in the area, and that the economic potential of the Scholle district is low.

Uranium also occurs with copper mineralization in the Abo Formation at the Mirabel copper and Ingersol mines in the Zuni Mountains, Cibola County (Fig. 23; Appendix 1). Uranium was first reported to occur in this area in 1952 (Gott and Erickson, 1952), and is also found in fault and shear zones in the underlying Precambrian granitic rocks (Fig. 23; Appendix 1). Although no uranium has been produced from this area, copper was first mined by Indians several hundred years ago (Lindgren and

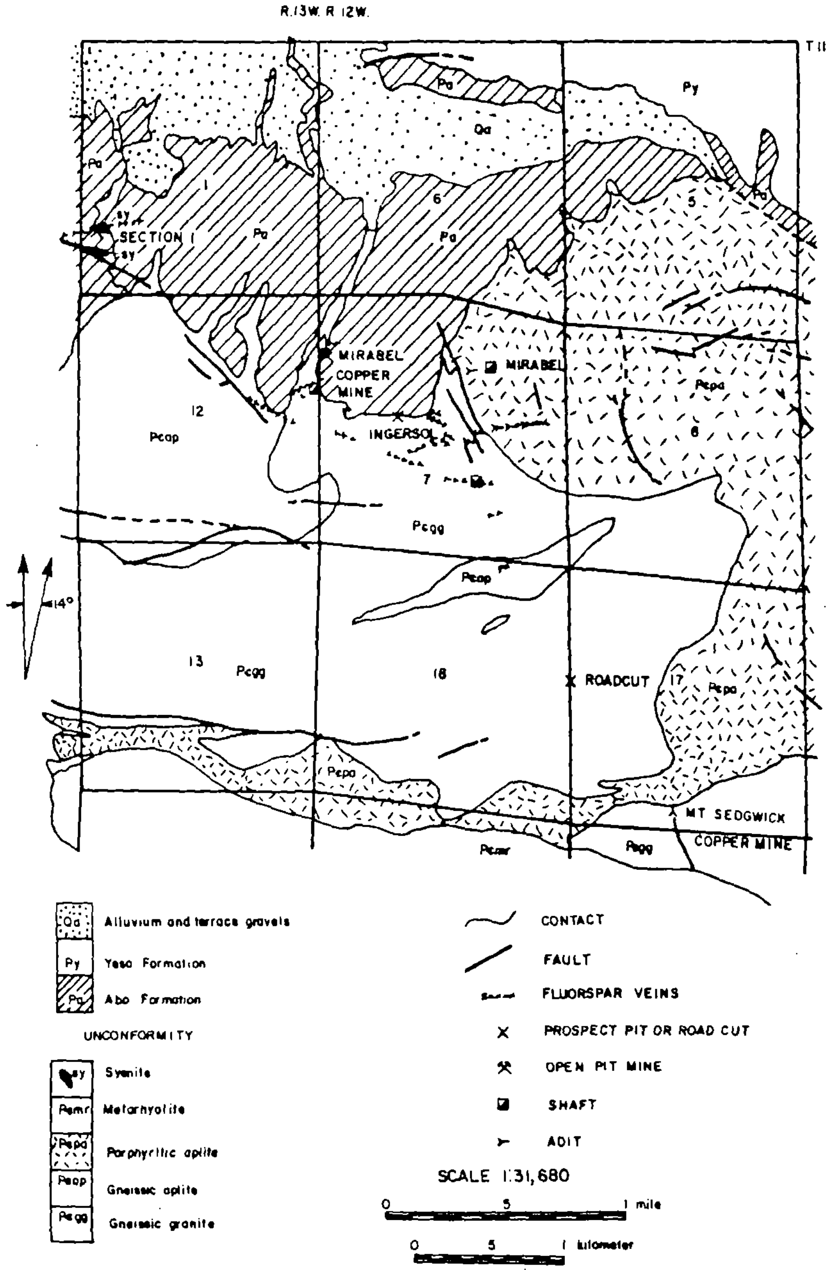


FIGURE 23 - SIMPLIFIED GEOLOGIC MAP SHOWING URANIUM IN THE ZUNI MOUNTAINS, CIBOLA COUNTY. MODIFIED FROM GODDARD (1966).

others, 1910). Since then copper, gold, and silver have been produced from this area, but production figures are not known.

Copper and uranium minerals replace wood fragments and organic debris in fluvial sandstones, which is typical of most Abo mineralization in New Mexico. Anomalously high uranium values occur in water and stream-sediment samples in this area (Maassen and LaDelfe, 1980) and radiometric anomalies were detected by an aerial reconnaissance of the area (Geometrics, Inc., 1979a). These anomalies may be attributed to additional sandstone deposits or to hydrothermal-vein deposits that occur in the area.

The Abo Formation in the Sierra Cuchillo, Sierra County, consists of basal conglomerates, sandstones, and limestones overlain by a thick shale sequence. The maximum thickness of the Abo Formation is approximately 920 ft (280 m; Jahns, 1955a). Six uranium occurrences are found in Abo sandstones, siltstones, and limestones (Appendix 1), and production from three of these occurrences amounts to 47 lbs (21 kg) of U_3O_8 (Appendix 3). Production from one property, State mining lease, assayed 0.16% U_3O_8. At the Glory No. 2 and Empire claims, uranium and copper minerals occur in silicified sandstones of the Abo Formation and in Tertiary rhyolite dikes. Production from these claims amounts to 28 lbs (17 kg) of U_3O_8 at an average grade of 0.18 (Appendix 3) and an unknown quantity of copper ore. The mineralization at Glory No. 2 and Empire claims is described as hydrothermal-vein deposits (Boyd, 1957); however, the permeability of the sandstones and presence of organic material influence deposition of mineralization.

In general, the lack of continuous permeable sandstones, the absence of abundant organic material, and the low grade and small size of known deposits suggest that economic ore bodies are unlikely to be found in the Sierra Cuchillo. However, ore bodies similar to the Glory No. 2 and Empire claims, that are related to Tertiary intrusives or volcanics, may occur in the Sierra Cuchillo.

Uranium, copper, lead, and zinc mineralization occurs in the Abo Formation in the Sacramento Mountains, Otero County (Appendix 1). The Abo Formation in this area is subdivided into three members, a basal conglomerate (0-300 ft = 15-91 m thick), a middle arkose (50-200 ft = 15-61 m thick), and an upper red shale (0-300 ft = 0-91 m thick). Most of the mineralization occurs in the middle arkose member in the Sacramento and Tularosa mining districts (Appendix 1; Jerome and others, 1965; LaPoint, 1976).

Uranium-copper mineralization is found in nodules, as replacements of woody material along bedding planes and fractures, and at sandstone-shale interfaces. However, lead and zinc mineralization is the dominant ore in the High Rolls area in the Sacramento mining district and accounts for most of the mineral production (Jerome and others, 1965). Significant amounts of copper and trace amounts of uranium are found with lead-zinc mineralization only at the Warnock mine, although low concentrations of copper may occur at other lead mines. Lead and zinc occur in minor quantities at copper mines. A sample from the Adycopt copper mine assayed 0.008% U_3O_8, 6.45% Cu, and 0.01% Pb (Appendix 2). North of the High Rolls area, up to 0.03% U3O8 is found at the Luz #2 occurrence (Appendix 2); lead and copper are present in minor quantities (Appendix 1).

The unique relationship between copper-uranium mineralization and lead-zinc mineralization is unclear. The structural history, presence of igneous rocks, and mineral assemblages suggest a hydrothermal origin (Jerome and others, 1965). However, no clear evidence of hydrothermal activity and no significant alteration are found adjacent to igneous dikes in the area. Although lead-zinc mineralization does not appear to be related to organic material, uranium-copper mineralization is. The absence of hydrothermal alteration, mineral associations, and ore-controlling features (sedimentary and bedding characteristics instead of fractures and faults) suggests a syngenic (Jerome and others, 1965) or hypogenic origin for the lead, zinc, copper, and uranium mineralization. Original groundwater flow or subsequent remobilization of uranium and copper could have formed copper deposits in areas of abundant organic material. Unfortunately, the subsurface potential, the source of mineralization, and the mineralization processes remain unclear.

In general, Pennsylvanian and Permian sediments in New Mexico are unfavorable for large, economic uranium deposits, except for the Sangre de Cristo Formation. Although numerous uranium occurrences are found in these rocks, they are low grade, small in extent, and occur in discontinuous and thin sandstones, siltstones, and limestones. Organic material is the primary limiting factor, as it occurs abundantly only locally. In contrast, the Sangre de Criso Formation contains ore bodies in braided-stream sandstones that tend to be regionally continuous and organic material is abundant. Past production from Pennsylvanian and Permian sediments is minor and future production is doubtful.

<u>Uranium in Triassic sedimentary rocks</u>

The majority of uranium occurrences in Triassic sedimentary rocks are found in the underlying Santa Rosa Sandstone and in the Chinle Formation in eastern New Mexico (Appendix 1). Although in Arizona more uranium was produced from the Chinle Formation than from any other unit (Scarborough, 1980, 1981), in New Mexico uranium mineralization in Triassic rocks is minor. The largest red-bed sandstone copper deposits of New Mexico are in the Chinle Formation (Soulè, 1956; L. A. Woodward, Kaufman, and others, 1974), however, less than 100 uranium occurrences are found in Triassic sedimentary rocks in New Mexico. The majority of these are in the Great Plains of eastern New Mexico and the Nacimiento Mountains in Rio Arriba and Sandoval Counties (Appendix 1). Less than 177 lbs (80 kg) of U_3O_8 have been produced from 5 mines in the Chinle Formation (Appendix 3). Uranium in Triassic rocks also occurs in the Chaco Basin-Llaves area in Rio Arriba County, and the East Mogollon Slope area in Catron County and adjacent eastern Arizona. Minor, isolated uranium occurrences are found in Cibola, Santa Fe, Socorro, and Lincoln Counties (Appendix 1).

In eastern New Mexico (Quay, San Miguel, Chaves, Lea, Guadalupe, and Harding Counties), the Triassic section consists of the Dockum Group, which contains (in ascending order) the Santa Rosa Sandstone, the Chinle Formation, and the Redonda

Formation. In western New Mexico (San Juan Basin), the Triassic section consists primarily of the Chinle Formation. However, in the Zuni Mountains the Moenkopi Formation underlies the Chinle, and in western New Mexico the Chinle is locally overlain by the Glen Canyon Group (Green and Pierson, 1977; O'Sullivan, 1977).

Only four uranium occurrences are found in the basal Santa Rosa Sandstone in eastern New Mexico (Appendix 1). The Santa Rosa Sandstone consists dominantly of medium-grained, calcareous sandstones, is about 150 to 200 ft (45 to 61 m) thick, and is subdivided into four members (V. C. Kelley, 1972). The uranium mineralization occurs in the middle and upper members (W. I. Finch, 1972). Uranium also occurs with the asphaltite deposits near Santa Rosa (Hail, 1955, 1957). Uranium mineralization is absent at the Stauber copper mine in Guadalupe County (Gott and Erickson, 1952).

In eastern New Mexico the Chinle Formation is about 400 to 1,200 ft (121 to 366 m) thick (V. C. Kelley, 1972) and contains the majority of the uranium deposits and occurrences found in Triassic rocks of New Mexico. In the Great Plains region the Chinle consists of three informal members; a lower shale, middle sandstone (locally called the Cuervo Sandstone Member), and an upper shale (V. C. Kelley, 1972; McLemore and Menzie, 1983). The lower member consists of interbedded grayish-red and greenish-gray shales, claystones, siltstones, and sandstones. The middle sandstone member consists of reddish-brown to maroon sandstones and gray limestone-pebble conglomerates separated by greenish-gray to maroon shales and siltstones. The upper member consists of thick-bedded, reddish-brown sandstones and siltstones separated by grayish-red and greenish-gray shales. The Chinle Formation in eastern New Mexico was probably deposited under arid conditions by a complex fluvial system with adjacent flood plains and lacustrine environments (McLemore and Menzie, 1983; Reid and others, 1980b).

Most of the uranium occurrences in the Chinle Formation of eastern New Mexico are found in sandstones, conglomerates, and limestones of the upper portion of the lower member and in the middle sandstone member (Appendix 1). Uranium mineralization occurs as disseminations within limestone-pebble conglomerates and sandstones, at sandstone-shale interfaces, and as halos surrounding clay galls. Organic material, clays, and structures such as folds appear to localize uranium, although these ore-controlling features are not important everywhere. Copper mineralization is rarely present.

Five areas in eastern New Mexico are favorable for low-grade uranium mineralization in the Chinle Formation. They are the Sabinoso district in San Miguel County (McLemore and Menzie, 1983); the San Jon, Tucumcari, and Forrest areas in Quay County; and central Lea County (U.S. Department of Energy, 1980). Uranium was produced from Chinle deposits in the Sabinoso district, San Jon, and Forrest areas (Appendix 3). One ore shipment from the Forrest area (Good Luck) in Quay County averaged 0.22% U_3O_8 (Appendix 1). Chemical analyses of up to 0.89% U_3O_8 (Hunt Oil) are reported from selected samples from the Sabinoso district (Appendix 2; McLemore and Menzie, 1983), and up to 0.15% U_3O_8 (Wallace Lease) in the San Jon area (Appendix 1).

However, most chemical analyses and average grades of ore shipments from other localities are less than 0.10% U_3O_8 (Appendix 1, 2).

It is doubtful that any large-tonnage, high-grade deposits with ore grades exceeding 0.10% U_3O_8 occur in the Chinle Formation in eastern New Mexico, despite estimates from the U.S. Department of Energy (1980). Small, low-grade deposits with ore grades ranging upwards to 0.10% U_3O_8 are probably common in these areas; however, the inaccessibility of many of these deposits and the high development and production costs would limit the economic feasibility.

The Redonda Formation consists of even bedded, orange-red, fine-grained sandstones and siltstones. It is about 50 to 200 ft (15 to 61 m) thick (V. C. Kelley, 1972). Only a few minor and isolated occurrences are found in this unit.

In northwestern New Mexico (San Juan Basin and adjacent areas), the Chinle Formation locally exceeds 1,640 ft (500 m) of thickness and consists of up to five members (O'Sullivan, 1977). In the southern San Juan Basin four members are present, in ascending order, Shinarump, Monitor Butte, Petrified Forest, and Owl Rock. Eastward, the basal Shinarump and Monitor Butte Members are absent and the Salitral Shale Tongue and Agua Zarca Sandstone are present. These two members are overlain by the Poleo Sandstone Lentil, Petrified Forest, and an unnamed siltstone member (O'Sullivan, 1974, 1977). These units extend into the Nacimiento Mountains. The Chinle Formation in the San Juan Basin was also deposited under arid conditions, in complex fluvial, lacustrine, and overbank environments similar to the depositional environments in eastern New Mexico.

In the Nacimiento copper and uranium minerals occur in lenticular channel sandstones in the Aqua Zarca Sandstone Member, Poleo Sandstone Lentil, and uppermost siltstone member (Appendix 1). The largest copper deposits in the Nacimiento Mountains occur in the Chinle Formation (L. A. Woodward, Kaufman, and others, 1974); however, only trace amounts of uranium mineralization are associated with the major copper deposits (Chenoweth, 1974b). About 18 uranium occurrences are found in the Chinle Formation in the Nacimiento Mountains and the Chama Basin-Llaves area. The Lucky Strike and Midcontinent prospects produced uranium ore from the upper Chinle Formation. Only 5 lbs (2 kg) of U_3O_8 at an average grade of 0.06% U_3O_8 were produced from these properties (Appendix 3).

Many of the uranium occurrences in the Nacimiento Mountains are associated with copper mineralization. Copper may be absent locally, especially in uranium deposits occurring in the Poleo Sandstone Lentil. It is doubtful whether any economic ore deposits occur in the Chinle Formation in the Nacimiento Mountains and Chama Basin-Llaves area because of the lack of continuity of the sandstones, lack of abundant organic material, low permeability and porosity of the sandstones, and the younger age of the Chinle sandstones in these areas as compared to older uraniferous sandstones in the lower Chinle Formation in Arizona.

Although no uranium occurrences have been found in the East Mogollon area in Catron County (Fig. 1), May and others (1980) and the U.S. Department of Energy (1980) speculate that undiscovered uranium deposits in the Chinle Formation occur in the subsurface. This area is the eastward, subsurface extension of the Cameron district in Arizona, where uranium has been produced from Chinle sandstones (Scarborough, 1980, 1981). Uranium in Arizona occurs as tabular, pod-like ore bodies in channel sandstones of the lower Chinle Formation and is associated with carbonaceous material and silicified logs in point-bar sequences near shallow synclines. Copper is absent, except at one locality in Arizona. There is no evidence available to confirm or dispute uranium mineralization in the Chinle Formation in this area.

Minor isolated occurrences are found in Cibola, Santa Fe, Socorro, and Lincoln Counties (Appendix 1). At the Blakely Ranch in Santa Fe County up to 0.065% U is reported to occur in conglomerates (Reid and others, 1980b). Elsewhere in the state secondary uranium minerals or radiometric anomalies occur (Appendix 1), but it is unlikely that these occurrences could have any economic potential.

Uranium in Cretaceous rocks

Deposits in the Burro Canyon Formation

In the Chama Basin a thin sequence of rocks lies between the Morrison Formation and the Dakota Sandstone. This sequence has been correlated by some authors with the Jackpile sandstone and by others with the lower Dakota Sandstone, however, it is best correlated with the Lower Cretaceous Burro Canyon Formation. The Burro Canyon Formation is lithologically similar to the upper

Morrison Formation except that the Burro Canyon is conglomeratic (Saucier, 1974). It consists of massive conglomeratic sandstones with thin discontinuous lenses of green and pink shales (Saucier, 1974; Green and others, 1980a; Ridgley, 1983). These are channel-bar and channel-fill deposits of a braided-stream environment (Green and others, 1980a).

Eight uranium occurrences are found in the Burro Canyon Formation, but none of them has produced any ore (Appendix 1). Uranium is generally associated with organic material and humates and limonitic staining. In the subsurface in sections 3, 4, 8, and 10, T. 25 N., R. 5 E., redistributed-ore occurs as fracture-controlled and roll-type mineralization (Saucier, 1974). Ore pods are small and low grade, and occur at depths of 200-600 ft (60-180 m). The U.S. Department of Energy (1980) believes that potential uranium resources may occur in this area.

Deposits in the Dakota Sandstone

More than 30 uranium occurrences are found in the Dakota Sandstone in the Laguna, Smith Lake, Ambrosia Lake, and Church Rock subdistricts of the Grants uranium district, and in Rio Arriba, Sandoval, San Miguel, San Juan, Catron, and Sierra Counties (Appendix 1); ten of these have produced 510,795 lbs (231,693 kg) of U_3O_8 (Table 4, Appendix 3). Most of these occurrences are found in the Church Rock, Smith Lake, and Ambrosia Lake subdistricts, and in the La Ventana area in Sandoval County.

The Dakota Sandstone is generally transgressive and intertongues with the Mancos Shale. It unconformably overlies the Brushy Basin Member throughout the Grants uranium district, except in the western portion of the Church Rock area where it unconformably overlies the Westwater Canyon Member. The Dakota Sandstone consists of thick-bedded quartz sandstones and thin carbonaceous shales, lignites, and coal lenses. The deposition took place in fluvial channels and backshore, paludal, coastal, and off-shore marine environments (Pierson and Green, 1980). It is 65 to 150 ft (20-45 m) thick.

Uranium mineralization in the Dakota Sandstone in the Grants district occurs as tabular masses that range in thickness from a few inches to 25 ft (8 m). Mineralization typically occurs with organic material at the base of channel sandstones along fractures, joints, or faults; beneath a clay lense or bed in sandstone, and in carbonaceous shales. Major uranium deposits in the Dakota Sandstone (Appendix 1) are always associated with (1) joints, fractures, or faults; (2) an underlying permeable (sandy) Brushy Basin Member; or (3) underlying Westwater Canyon Member (Pierson and Green, 1980). Additional uranium mineralization is commonly present in the underlying Westwater Canyon or Brushy Basin Members. Pb/U isochron dating indicates that Dakota mineralization is less than 0.8 m.y. (Ludwig and others, 1977, 1980). These features suggest that uraniferous waters, probably from the Westwater Canyon or Brushy Basin Members, migrated upwards along fractures, joints, or faults, or through permeable sandstones and deposited uranium in permeable Dakota sediments containing carbonaceous material or in carbonaceous shales (Pierson and Green, 1980).

Additional uranium deposits may be present in the Dakota Sandstone, especially in areas of faulting, jointing, and fracturing. However, most of these undiscovered deposits are likely to be small- to medium-sized, similarly to the known deposits in the Dakota Sandstone.

In the La Ventana area, uranium production from the Butler Brothers mine amounts to 290 lbs (132 kg) of U_3O_8 that averaged 0.63% U_3O_8 (Appendix 3). Uranium mineralization occurs in carbonaceous shale and lignite lenses in the Dakota Sandstone. Additional uranium occurrences are found in the Dakota Sandstone and in the Menefee Formation in the vicinity of the Butler Brothers mine (Appendix 1). At the Cleary prospect, uranium occurs within carbonaceous shale and peat layers at the base of the Dakota Sandstone (Appendix 1). A selected sample from the Cleary prospect contained 0.038% U_3O_8 (Appendix 2). Although small deposits of economic grade (greater than 0.10% U_3O_8) may occur in the La Ventana area, the potential for large, economic deposits is poor due to the low grade and thinness of the shale layers.

Deposits in other Cretaceous rocks

More than 30 uranium occurrences are found in Cretaceous rocks other than in the Burro Canyon Formation, Dakota Sandstone, and upper Crevasse Canyon Formation (Appendix 1). The majority of these uranium occurrences are in sandstones, carbonaceous shales, and lignites-coals in the Mancos Formation (Mesaverde Group), and Fruitland Formation in McKinley, Cibola, San Juan, Sandoval, Bernalillo, Sierra, and Lincoln Counties. These occurrences are usually isolated, small, and low grade. It is doubtful whether any of them could have any economic potential. However, two areas, the Boyd prospect in San Juan County and La Ventana area in Sandoval County, contain high concentrations of uranium and may have economic potential.

The Boyd prospect is located northwest of Farmington in San Juan County and is included on the San Juan Coal Company's mining lease. In 1955, 74 lbs (34 kg) of U_3O_8 at an average grade of 0.05% U_3O_8 were produced from this mine (Appendix 3). One 10 ton (9 metric tons) shipment assayed 0.10% U_3O_8. The uranium mineralization is finely disseminated and occurs at the base of a 20- to 30-ft (6- to 9-m) thick sandstone (Fig. 24) belonging to the lower Kirkland or upper Fruitland Formations. Hematitic alteration and finely disseminated organic material are associated with uranium mineralization. A selected sample assayed 0.182% U_3O_8 (Appendix 2), but assays up to 0.22% U_3O_8 are reported (Chenoweth, 1958).

The stratigraphic position of this occurrence has been the subject of some controversy. The massive brown, uraniferous sandstone has been correlated with the Pictured Cliffs Sandstone, the Kirkland Formation, and the Fruitland Formation (Chenoweth, 1958). The mineralized sandstone rests on a fossiliferous bluish-gray lag conglomerate and gray to bluff shale. Continental fluvial environments are indicated by vertebrate, mollusk, and plant fossils, thereby eliminating the Pictured Cliffs correlation. The absence of coal beds overlying the mineralized sandstone suggests correlation with lower Fruitland Formation,

Figure 24 - Mineralized sandstone of the lower Kirkland or upper Fruitland Formations at the Boyd prospect in San Juan County. This sandstone rests on a fossiliferous bluish-gray lag conglomerate and gray to bluff shale.

however, additional stratigraphic studies are required.

The Boyd prospect is unique, as there is no other major uranium occurrence in middle Cretaceous rocks in the central San Juan Basin, excluding minor isolated occurrences in coal beds. The origin of mineralization is not known but may be related to faulting in the vicinity. The economic potential of the Boyd prospect is probably low judging from low-grade ore shipments and thin mineralized zones at the surface. However, subsurface extent of this mineralized zone is unknown.

The La Ventana area lies south of Cuba in Sandoval County. Uranium occurs in coal, carbonaceous shale, and carbonaceous sandstone in the Upper Cretaceous Menefee Formation of the Mesaverde Group (Appendix 1; Bachman and others, 1959; Green and others, 1980c). The La Ventana tongue of the Cliff House Sandstone overlies the Menefee Formation and the basal contact may be locally mineralized (Green and others, 1980c). Uranium also occurs in the older Dakota Sandstone at La Ventana.

At least three mineralized horizons occur at La Ventana, and the highest uranium content is in the coal seams. Concentrations as high as 0.62% U_3O_8 may be found in coal, whereas the coal ash has uranium concentrations as high as 1.34% (Bachman and others, 1959; Vine and others, 1953). Mineralized zones are thin and range in thickness from a few inches to 1.5 ft (0.5 m). The absence of structure control of these uranium deposits is indicative of supergenic (Bachman and others, 1959) or hypogenic origins. Bachman and others (1959) estimates that 132 tons (120 metric tons) of U_3O_8 in coal and carbonaceous shale at an average grade of 0.10% uranium are found at La Ventana mesa. The reliability of this estimate is unknown.

Deposits in the Crevasse Canyon Formation

Although the majority of the 28 uranium occurrences in the Cretaceous Crevasse Canyon Formation are found in the Gallinas Mountains, Datil Mountains, and Quemado-Pie Town area, Socorro and Catron Counties, nine uranium occurrences are in shales and coal seams in the Church Rock, Smith Lake, and Ambrosia Lake subdistricts of the Grants uranium district in McKinley County (Appendix 1). These occurrences are isolated, small, and low grade, and do not have any significant uranium potential. However, sandstones in the upper Crevasse Canyon Formation in the Gallinas Mountains, Datil Mountains, and Quemado-Pie Town area do have a significant uranium potential. Uranium production from deposits in the Crevasse Canyon Formation in the Datil Mountains and Quemado area amounts to 1,194 lbs (542 kg) of U_3O_8 at an average grade of 0.12% U_3O_8 (Appendix 3). In addition, potential uranium resources in the Datil Mountains from the Crevasse Canyon and Tertiary Baca Formations have been estimated by the U.S. Department of Energy (1980).

The Crevasse Canyon Formation consists of interbedded sandstones, siltstones, shales, and coal seams deposited in a coastal-plain environment. In the uppermost Crevasse Canyon Formation in Socorro and Catron Counties lies an altered or transition zone of bleached and oxidized sandstones and shales, which is truncated by an unconformity (Chamberlin, 1981a, b, c).

The unconformity separates the Crevasse Canyon Formation from the overlying Baca Formation and is typically expressed by an abrupt change in grain size from medium-grained Cretaceous sandstones to Tertiary conglomeratic sandstones (R. M. Chamberlin, pers. commun., 1983). The altered or transition zone has been mapped in the Datil Mountains and Quemado area by Chamberlin (1981a, b) and Guilinger (1982), and is believed to extend into the Gallinas Mountains to the east and the Pie Town area to the west. This zone may extend into the San Juan Basin; however, additional mapping in this area is required to verify any altered or transition zones. The altered or transition zone was previously interpreted as (1) reworked Cretaceous rocks assigned to the overlying Baca Formation (New Mexico Geological Society, 1959), (2) an intertonguing Baca-Crevasse Canyon contact, (3) an altered zone formed by oxidizing ground waters (Pierson and others, 1981), and (4) a paleosol or weathering profile (Chamberlin, 1981a, b).

The interpretation of this transition zone is important because all of the major uranium occurrences in the Gallinas Mountains, Datil Mountains, and Quemado-Pie Town area are found in it. Uranium occurs only in trace amounts in coals and carbonaceous shales below this zone in Socorro and Catron Counties (Bachman and Reid, 1952a; personal reconnaissance, 1980-1982). In the Red Basin area of the Datil Mountains and in the Pie Town-Quemado area this transition zone is well developed and has been mapped by Chamberlin (1981). Small ore bodies have yielded ore from 1954 to 1957 (Appendix 3), and additional small ore bodies were discovered by Gulf Minerals in the early 1970's

(Appendix 1; Chamberlin, 1981a, b). In the Gallinas Mountains only small and isolated occurrences are found in the Crevasse Canyon Formation (Appendix 1); most of the uranium potential is concentrated in the overlying Baca Formation. However, the potential of the Crevasse Canyon Formation in the subsurface has not been adequately examined.

The uranium deposits in the Crevasse Canyon Formation are typically small (less than several thousand tons of U_3O_8), and are associated with organic material, iron staining, clay galls, and sandstone-shale interfaces (Appendix 1; Collins, 1958a; Chamberlin, 1981a, b). Selected samples contain as much as 0.024% U_3O_8 (Appendix 2), although reported assays are as high as 1.28% U_3O_8 (Collins, 1958a). The presence of ghost rolls (Chamberlin, 1981a, b) indicates that roll-type uranium deposits are likely to occur in the subsurface.

Deposits in lower Tertiary Rocks

More than 30 uranium occurrences are found in lower Tertiary sediments in New Mexico. These occurrences are found within several hundred feet above an unconformity on Cretaceous rocks. Production from Tertiary sediments at two properties in Socorro and San Juan Counties amounts to 354 lbs (161 kg) of U_3O_8. Uranium occurrences are found in the Baca Formation, Ojo Alamo Sandstone, Galisteo Formation, and McRae Formation in Socorro, Catron, San Juan, Sandoval, Rio Arriba, and Sierra Counties (Appendix 1).

Only one property, the Hook Ranch mine in Socorro County, produced from the Eocene Baca Formation; the production amounted to 3Ø6 lbs (139 kg) of U_3O_8 at an average grade of Ø.18%. Some production from the Red Basin Group in Catron County may have been derived from the Baca Formation, although the majority of the ore produced was from the underlying Crevasse Canyon Formation. At least 14 additional uranium occurrences are in the Baca Formation in the Gallinas-Bear Mountains, Datil Mountains, and Pie Town-Quemado area (Appendix 1).

The Baca Formation unconformably overlies the Cretaceous Crevasse Canyon Formation and consists of mudstones, siltstones, sandstones, and conglomerates of braided-alluvial plain, meander belt, and lacustrine environments (Cather, 198Ø). Uranium mineralization is associated with carbonaceous material, carbonaceous shale lenses, or fossil logs in fluvial sandstones and conglomeratic sandstones in the middle and lower members of the formation. Chemical analyses as high as 3.27% U_3O_8 are reported from mineralized lenses in the Baca Formation (New Mexico Geological Society, 1959); however, samples collected by the author contained less than Ø.Ø2% U_3O_8 (Appendix 2).

In the Riley area of the Bear Mountains, Socorro County, uranium mineralizatio is closely associated with organic material in reduced sandstones of the middle member of the Baca Formation. Detailed drilling has delineated several ore bodies which contain a few hundred thousand lbs of uranium ore exceeding Ø.1Ø% U_3O_8 (Don Sargent, consulting geologist, written commun., 1983). Widely spaced drilling has outlined an adjacent area of favorable reduced sandstones.

Potential uranium deposits are likely to occur in the upper Crevasse Canyon Formation in the Red Basin area and in the Baca Formation in the Riley area of the Bear Mountains. Additional drilling in the Baca and Crevasse Canyon Formations may delineate additional favorable areas.

The Paleocene(?) Ojo Alamo Sandstone crops out in the San Juan Basin and consists of 20 to 400 ft (6-120 m) of fluvial sediments. The Ojo Alamo Sandstone rests unconformably on the Cretaceous Kirkland Formation and is overlain by the Nacimiento Formation (Green and others, 1980a, c). Only one property, Claim #14 in San Juan County, has any recorded production, which amounts to 48 lbs (22 kg) of U_3O_8 at an average grade of 0.11% U_3O_8 (Appendix 3). Unfortunately, this property can no longer be located.

The greatest uranium potential in the Ojo Alamo Sandstone is in the Mesa Portales area in Sandoval County (Appendix 1). Although only a few minor and unverified uranium occurrences have been reported at Mesa Portales (Appendix 1), radiometric anomalies are detected by water, stream-sediment, and aerial-radiometric studies (Green and others, 1980a, c). Recent drilling at Mesa Portales indicated that low-grade uranium occurs in blanket-like bodies in several horizons. The lack of a clear mineralization pattern may suggest that these deposits are modified roll-type or remnant ore bodies (Green and others, 1980a, c). Favorable criteria such as abundant carbonaceous material, permeable fluvial sandstones, and favorable geometry of host rocks suggest that the Ojo Alamo Sandstone is favorable for containing uranium deposits. Despite the absence of proven economic uranium mineralization (over 0.10% U_3O_8; Green and others, 1980a, c), the U.S. Department of Energy (1980) estimates that some potential uranium resources occur in the Mesa Portales area.

Seven uranium occurrences are found in the Eocene Galisteo Formation in the Hagan Basin, Sandoval County (Appendix 1; McLemore, 1982c). Although these deposits have not yielded any ore, the U.S. Department of Energy (1980) believes some potential resources are present in this area. The Galisteo Formation consists of fluvial-lacustrine sandstones, siltstones, conglomerates, and tuffs, and ranges in thickness from 900 to 4,000 ft (275-1,200 m). These sediments rest unconformably on the Cretaceous Mancos Shale (Mesaverde Group) and are overlain by the Espinaso Volcanics. Uranium-bearing latite dikes and sills, probably related to the Espinaso Volcanics, intrude this sequence.

Uranium mineralization in the Galisteo Formation occurs in high-energy, braided-stream sediments of a complex alluvial-fan sequence. Uraninite and coffinite occur as sand coating in roll-type ore bodies (J. C. Moore, 1979). One of these ore bodies is estimated to contain 0.9 million lbs (410,000 kg) of U_3O_8 at an average grade of 0.09% U_3O_8 at depths of 10-400 ft (3-120 m; J. C. Moore, 1979). One sample from the ore pile at the Diamond Tail decline in this area assayed 0.064% U_3O_8 and a trace of Se (Appendix 2).

High production costs, low-grade ore, environmental costs, and a declining uranium market forced Union Carbide to abandon uranium mining in this area. Mining may resume if economic conditions improve.

A few isolated uranium occurrences are found in sandstones of the McRae Formation of Late Cretaceous to early Tertiary age in Sierra County (Appendix 1). The McRae Formation is divided into the basal Jose Creek Member and the overlying Hall Lake Member. The Jose Creek Member consists of gray shales, sandstones, and conglomerates, and is Cretaceous in age. The overlying Hall Lake Member is Tertiary in age and consists of purple shales and interbedded sandstones and conglomerates. Uranium concentrations at these localities are less than 0.02% U_3O_8 (Templain and Dotterrer, 1978). Very little additional information exists concerning these ocurrences because they lie on the private Pedro Armendaris Land Grant and consequently have not been examined in detail. If the McRae Formation is similar in age and lithology to the Crevasse Canyon and Baca Formations in Socorro and Catron Counties (Chamberlin, 1981a, b), then also the uranium occurrences may be similar to those in the Crevasse Canyon and Baca Formations.

Deposits in upper Tertiary and Quaternary rocks

Much of the uranium potential occurs in lower Tertiary sediments (discussed above). Less than 50 uranium occurrences are found in Tertiary and Quaternary sediments (Appendix 1), in the San Jose Formation, Popotosa Formation, Santa Fe Group, Tesuque Formation, Carson Conglomerate, Ogalla Formation, and Recent hot springs deposits. All of these occurrences are small and low grade. Two of these, the San Jose #13 in Santa Fe County and San Lorenzo #1 in Socorro County, have yielded ore amounting to 18 lbs (8 kg) of U_3O_8 at grades averaging less than Ø.Ø5% U_3O_8.

Most of these occurrences are found in the Tesuque Formation of the Santa Fe Group in Santa Fe County (Appendix 1). Sediments of the Tesuque Formation were derived from the Precambrian rocks in the Sangre de Cristo Mountains and volcanic rocks in the Jemez Mountains (Hilpert, 1969). These occurrences probably represent accumulations of uraniferous ground waters. Uranium may have been derived from the Sangre de Cristo Mountains, the Jemez volcanics, or alteration of detritus in the host rocks. Uranium typically occurs as coatings around opal and chert grains, with organic debris, and in clay zones. One property, the San Jose #13 in Santa Fe County, yielded 12 lbs (5 kg) of U_3O_8 at an average grade of Ø.Ø5% U_3O_8 in 1957 (Appendix 3). It is unlikely any large economic deposits (greater than Ø.1Ø% U_3O_8) could occur in these sediments because insufficient time has elapsed to form large uranium deposits.

Uranium mineralization is found in the Popotosa Formation in Socorro County (Appendix 1). Anomalous concentrations of lithium are also found in ash beds of the Popotosa Formation and are locally associated with uranium mineralization (Appendix 1). The San Lorenzo #1 yielded 6 lbs (3 kg) of U_3O_8 at an average grade of Ø.Ø2% U_3O_8 (Appendix 3) from a chert bed in the Popotosa Formation. The economic uranium potential in these rocks is poor because of their low grade and small size.

The Nacimiento Formation in northern New Mexico overlies the

Ojo Alamo Formation and is in turn overlain by the San Jose Formation. The lower contact with the Ojo Alamo Formation is gradational and intertonguing. An angular unconformity separates the Nacimiento and the overlying San Jose Formations (Green and others, 1980a, c). Only one occurrence (Anomaly NA-17, Rio Arriba County) is found at the contact of these formations; however, radiometric anomalies have been detected by hydrogeochemical and aerial-radiometric studies (Green and others, 1980a, c). Favorable host-rock characteristics, abundant carbonaceous material, low dip of beds, and radiometric anomalies indicate that this unit may contain uranium deposits. However, the lack of known large uranium ore bodies suggests that ground waters were not significantly enriched in uranium (Green and others, 1980a, c).

Twelve uranium occurrences are found in the San Jose Formation in Sandoval, Rio Arriba, and San Juan Counties (Appendix 1). Uranium is associated with carbonaceous material in fluvial sandstones and one coal seam. The permeable fluvial sandstones are persistent laterally and carbonaceous material is abundant. A few uranium anomalies were detected by hydrogeochemical studies (Green and others, 1980a). However, despite favorable characteristics of this unit, large economic ore bodies have not been found.

Seven radioactive hot springs deposits are found in Sandoval, Dona Ana, and Grant Counties (Appendix 1). They occur as travertine or tufa and are being deposited at the present time. Although these uranium occurrences do not have economic potential, they are significant because they indicate a source of uranium in the present environment. One sample from Soda Dam in Sandoval County contains 0.001% U_3O_8 and 35.9% Ca (Appendix 2). Numerous hot springs occur along the Rio Grande valley and in the Mogollon Plateau region; the uranium content or radioactivity are unknown for most of them.

Limestone Deposits

Uraniferous limestones, exclusive of the Todilto Limestone, are not common in New Mexico. Most uranium in limestones (exclusive of the Todilto Limestone) is of a vein-type of uncertain origin and is described elsewhere. However, two areas, the Rocky Arroyo area in Eddy County and Union County, contain uranium occurrences in limestone and additional favorability criteria to be considered as favorable for containing uranium deposits.

Uranium occurs at four localities in the Rocky Arroyo area near Carlsbad (Appendix 1). It is associated with asphaltite pellets within sandstones, dolomites, and dolomitic limestones of the Permian Yates and Seven Rivers Formations. The age of mineralization is Permian, similar to the age of the host rocks (Pierce and Roshalt, 1961; Sam Thompson and Alonso Jacka, pers. commun., 11/19/81). One sample collected from the Rocky Arroyo prospect assayed 0.017% U_3O_8 and 0.7% organic carbon (Appendix 2), but assays as high as 2.3% U_3O_8 have been reported (Waltman, 1954). In 1980, the U.S. Department of Energy (1980) considered this area as favorable for potential uranium resources; however, low grades, small tonnages, and long haulage distances to existing mills would hamper development of these deposits.

The Yates and Seven Rivers Formations are representative of the back reef environment of the marine Capitan Limestone reef complex (Pierce and Roshalt, 1961; Alonso Jacka, pers. commun., 11/19/81). The asphaltite and associated uranium mineralization were deposited shortly after dolomitization of the limestone (Roy Foster, Petroleum Research and Recovery Center, pers. commun., 1981; author's thin-section analysis). These occurrences do not appear to have any lateral continuity. All four occurrences are minor, and gamma-log anomalies in oil and gas tests, thought to represent similar occurrences in the subsurface (Waltman, 1954), cannot be correlated between adjacent wells.

Uraniferous marlstones of the Jurassic Morrison Formation occur in eastern Union County and adjacent western Oklahoma (Consulting Professionals, Inc., 1980; Abbott, 1975). At least four localities of uranium-bearing marl are found in Union County (Appendix 1); additional occurrences are in Oklahoma. Chemical analyses of samples of this marlstone range up to 260 ppm U (Abbott, 1975; Consulting Professionals, Inc., 1980). Additional detailed studies of this area would probably reveal similar occurrences.

Uranium occurs in dense marlstone and may be associated with disseminated organic particles (Consulting Professionals, Inc., 1980). This unit is approximately 82 to 112 ft (25-34 m) above the base of the Morrison Formation and locally splits into two marlstone beds separated by 9 to 15 ft (3-4.5 m) of siltstone and mudstone. These uraniferous marlstones appear to be continuous throughout Union County (Consulting Professionals, Inc., 1980).

However, the units are thin (less than 3 ft = 1 m) and low in grade (less than 0.01% U_3O_8) and would not constitute a significant economic uranium source at the present time. The U.S. Department of Energy (1980) estimates that potential resources (classified incorrectly as sandstone deposits) exist in the area.

Beach-Placer Sandstone Deposits

Beach-placer sandstone deposits are concentrations of heavy minerals that form on beaches or in long-shore bars in a marginal-marine environment (Mickle and Mathews, 1978; Mickle, 1978; Mathews and others, 1979). Numerous beach-placer sandstone deposits are found in northern New Mexico (Table 6, Appendix 1), and at least three wells have penetrated similar deposits in the subsurface (Chenoweth, 1957a). All of these deposits except the Cimarron deposit in Colfax County are in the San Juan Basin (Fig. 25). Although beach-placer sandstone deposits are found in strata of all ages; the deposits in New Mexico are restricted to Upper Cretaceous rocks in the Gallup, Dalton, Point Lookout, Pictured Cliffs, and Trinidad Sandstones (Chenoweth, 1957a; Houston and Murphy, 1977).

The beach-placer sandstones are radioactive due to radioactive zircon, monazite, and columbium minerals. In addition, minerals such as ilmenite, anatase, leucoxene, magnetite, hematite, zircon, garnet, and tourmaline are common in these sandstones. Anomalously high concentrations of Ti, Fe, Sc, Nb, Th, U, and rare-earth elements are charateristic. These

Table 6 - Beach-Placer Sandstone deposits in New Mexico

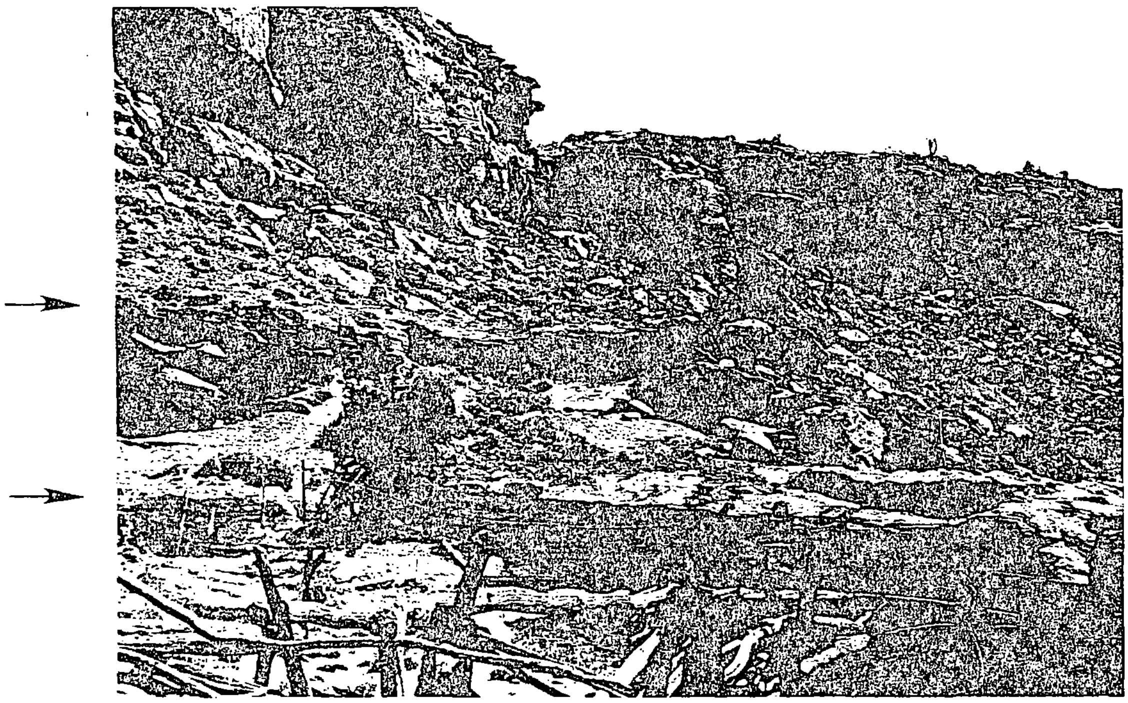
Occurrence Number	Name	County	Host
26N.19S.6	Cimarron	Colfax	Trinidad Sandstone
28N.1E.3.311, 28N.1E.3.323	Airbourne Anomalies #12 (Stinking Lake)	Rio Arriba	Point Lookout Sandstone
17N.4W.34.332	B.P. Hovey Ranch (Torreon Wash)	Sandoval	Point Lookout Sandstone
12N.2W.31.420	Herrera Ranch	Sandoval	Gallup Sandstone
11N.2W.16.200	Herrera Ranch	Bernalillo	Point Lookout Sandstone (?)
15N.19W.32.432	Gallup titanium deposit (Defiance)	McKinley	Gallup Sandstone
19N.6W.13,14, 19N.6W.15.340 19N.6W.23.344 19N.6W.25,26	Farr Ranch (Star Lake)	McKinley	Pictured Cliffs Sandstone
15N.6W.4.140, 8.420	Miguel Creek Dome	McKinely	Dalton sandstone member (Crevasse Canyon Formation)
18N.14W.35.300	Standing Rock	McKinely	Point Lookout Sandstone
31N.14W.13	Anomaly #4 Barker Dome	San Juan	Pictured Cliffs Sandstone
30N.15W.6 30N.16W.32 30N.16W.10.340 31N.16W.24 31N.15W.30 31N.15W.30 31N.15W.30 31N.15W,19.400 31N.16W.14 31N.16W.15 31N.16W.3.100 31N.16W.3.200, 30N.15W.6	Anomaly #5,6,7,8, 9,10,11,12,13-15 16-18,19-20,21, near 21, Deposit x-y, #2	San Juan	Point Lookout Sandstone
32N.16W.28 32N.16W.28	Anomaly #22-23 (Salt Creek Wash), Near #23	San Juan	Point Lookout Sandstone
32N.16W.29 32N.17W.27 32N.17W.15 32N.17W.27 32N.17W.22,27 31N.16W.15,16 31N.16W.10, 32N.16W.19	Anomaly #24,32, 33,34,35,36,37, Deposit #2	San Juan	Point Lookout Sandstone
28N.17W.13	Anomaly #46	San Juan	Point Lookout Sandstone
30N.16W.15.323	Hogback #2	San Juan	Point Lookout Sandstone
26N.19W.31	Sanostee	San Juan	Gallup Sandstone
23N.19W.14	Tordlena	San Juan	Gallup Sandstone

sandstones range from olive-gray, rust-brown, brownish-black to maroon, and occassionally are called "black sandstone deposits." Beach-placer sandstone deposits occur at the top of beach sandstones and at places in two or more intervals (Fig. 26).

Only one locality in New Mexico, the Hogback #2 property (30N.16W.15.323, Appendix 1) in San Juan County, has been mined; where 8 tons (7 metric tons) of "no-pay" ore yielding 3 lbs (1 kg) of U_3O_8 (0.02%) was produced from the Point Lookout Sandstone in 1954 (Appendix 3). Many of the beach-placer sandstone deposits in New Mexico are low-tonnage and low-grade and remain undeveloped. However, it is estimated that a total of 4,751,200 tons (4,310,200 metric tons) of ore containing 12.82% TiO_2, 2.07% ZrO_2, 15.51% Fe, and less than 0.10% $eThO_2$ (radiometric equivalent ThO_2) are present in the San Juan Basin in New Mexico (Dow and Batty, 1961). The reliability of this estimate is uncertain. Additional deposits probably remain undiscovered in the area. The small size and low-grade of individual deposits prevent large-scale mining of them despite their economic potential.

In addition, Recent beach-placer sandstone deposits in Florida and Georgia are mined for titanium, and thorium is recovered as a by-product from monazite. Monazite from these deposits constitutes only 0.3 to 1.0% of the heavy minerals recovered. Thorium may be as high as 5% in the monazite. Thus the amount of thorium produced in the future will probably come from these recent deposits or as by-product of other mining ventures.

Figure 26 - Beach-placer sandstone deposits at B.P. Hovey Ranch in the Torreon Wash area, Sandoval County, Arrow points to two separate intervals at the top of the beach sandstones.



Miscellaneous deposits in sedimentary rocks

Uraniferous nopedogenic calcretes

Although uraniferous nonpedogenic calcretes have not been reported to occur in New Mexico, Carlisle and others (1978) estimate the probability of their presence in the Mimbres-Palomas Basin in Luna County, New Mexico to be fair. Nonpedogenic calcrete is a mixture of secondary carbonate and smectite replacing alluvium, soil, or other regolith deposits in semiarid to subhumid climate. Nonpedogenic calcretes should not be confused with caliche or other calcareous soils, although both are similar in composition and texture and both form in oxidizing environments. Nonpedogenic calcretes, unlike caliches, are not formed by soil processes, but are formed by lateral movement of carbonate-enriched fluids instead of by vertical transport, and are therefore nonpedogenic. Uraniferous calcretes have only recently been discovered; they are economically important in Western Australia and the Namib Desert of South West Africa (Carlisle and others, 1978; Mickel and Mathews, 1978).

Uraniferous calcretes occur along the axial portions of fluvial valleys in a dry climate with seasonal rainfall. Evaporation rates are high and of the limited runoff is largely confined to subsurface drainage basins. Groundwaters are characteristically enriched in carbonate, uranium, and vanadium. Groundwaters near calcrete deposits in Western Australia contain 15-70 ppb U and 3-12 ppb V (Carlisle and others, 1978). Carnotite is the dominant uranium mineral present in known uraniferous calcretes, although soddyite has been reported to occur in South West Africa. Absence of soil carbonate deposits or other uranium-fixing processes in the catchment area is essential. Uraniferous calcretes occur in constricted shallowing or upwelling of the groundwater flow within the catchment area (Carlisle and others, 1978). Preservation of the uranium mineralization requires tectonic and climatic stability and protection of mineralization from subsequent dissolution (Carlisle and others, 1978).

In southern New Mexico a uraniferous source terrain is present in the Burro, Caballo, Organ, and Tres Hermanos Mountains (Appendix 1). Well-water analyses (Union Carbide Corp., 1981L) range from Ø to 9 ppb, in uranium content in contrast to uranium concentrations in well waters near Waterloo which range up to 288 ppb U (Carlisle and others, 1978, p. 245). Seven, shallow (11 ft = 3 m) backhoe trenches dug by Carlisle and others (1978) in this area failed to locate any nonpedogenic calcrete or anomalous uranium-bearing rocks, although calcrete deposits may exist at depth.

Additional areas, especially in sediments of the ancient Rio Grande (Giles and others, 1981, p. 66), may contain calcrete deposits which should be examined for their uranium potential. A valley calcrete deposit west and south of the Ladron Mountains in Socorro County is currently being examined by James Barker (New Mexico Bureau of Mines and Mineral Resources). This deposit was previously interpreted as a travertine deposit, but it lacks the apron-shaped geometry typical of most travertine deposits and displays characteristics typical of valley calcretes (J. M.

Barker, 1983). The presence of a uraniferous source in the Ladron Mountains suggests a potential for nonpedogenic calcrete uranium deposits in this area. However, tectonic stability is a major requirement for uraniferous calcretes in Western Australia (Carlisle and others, 1979), and it is lacking in northwestern Socorro County and elsewhere in New Mexico.

Precambrian Quartz-pebble conglomerate deposits

Early Proterozoic quartz-pebble conglomerates in Witwatersrand, South Africa and Blind River-Elliot Lake district, Ontario, contain significant uranium deposits (Mickel and Mathews, 1978). These deposits typically occur in lower Proterozoic sediments that range in age from 2.2 to 2.7 b.y. and are adjacent to Archean source terrains (Button and Adams, 1981). Uraninite and brannerite are the dominant ore minerals. It is believed that uraniferous quartz-pebble conglomerates were formed before 1.8 to 2.0 b.y. ago, when the atmosphere contained insufficient oxygen to allow oxidation and dissolution of uranium minerals.

Several areas in New Mexico are known to contain Precambrian quartz-pebble conglomerates. The absence of uranium occurrences, the absence of uraninite and pyrite in the conglomerates, the young age (1.8 b.y. or younger), and the absence of Archean source rocks in southwestern United States indicate low probability for uraniferous Precambrian quartz-pebble conglomerates in New Mexico.

Phosphorite deposits

Phosphorites are sedimentary rocks that contain more than 20% of phosphatic minerals and were typically deposited in a marine environment. Average grade of uranium in these deposits ranges from 0.005 to 0.03% (Mickle and Mathews, 1978). Phosphate deposits in west-central Florida are currently being mined for their phosphate content and uranium is recovered as a by-product. Phosphate deposits within the Permian Phosphoria Formation in Idaho, Montana, Wyoming, Utah, and Nevada may contain 0.001 to 0.65% uranium. Unfortunately, rocks typical of the Florida deposits and of the Phosphoria Formation are absent in New Mexico.

Deposits in Intrusive Igneous and Metamorphic Rocks

Uranium deposits in intrusive igneous and metamorphic rocks

Introduction

More than 200 uranium occurrences represent orthomagmatic, contact-metasomatic, anatectic, and hydrothermal-vein (magmatic-hydrothermal, authigenic, and allogenic deposits of NURE; Mathews, 1978) uranium deposits in Precambrian granitic rocks, Tertiary intrusives and volcanics, and metamorphic rocks (Appendix 1). In addition to these occurrences, more than 80 thorium veins, more than 25 pegmatites, and 3 carbonatite dike complexes are found in New Mexico and are described separately. Uranium production from 12 properties amounts to 28,595 lbs (12,970 kg) of U_3O_8 at an average grade of 0.14% U_3O_8 (Appendix 3); most of this production is from the La Bajada mine in Santa Fe County.

Although some of the world's largest potential resources of uranium occur in igneous and metamorphic rocks, the potential for uranium and thorium deposits in igneous and metamorphic rocks in New Mexico has not been well examined. Many of the NURE quadrangle reports (Table 1) have not adequately evaluated potential host rocks, and only one area in New Mexico, the Burro Mountains in Grant County, is believed to contain potential uranium resources (U.S. Department of Energy, 1980; O'Neill and Thiede, 1981). The majority of uranium occurrences in igneous and metamorphic rocks in New Mexico are found in Precambrian granitic rocks, Tertiary intrusives and volcanics, copper veins, fluorite veins, and metamorphic or altered sediments (Appendix 1). Several areas in New Mexico may be favorable for containing uranium deposits in igneous and metamorphic rocks (McLemore, 1982a), however, many of these areas have not been mapped in detail, nor has the uranium potential been adequately assessed. A few of these areas are described here.

Uranium in Precambrian granitic rocks

The majority of the uranium occurrences in igneous and metamorphic rocks in New Mexico are found in Precambrian terrains (Appendix 1; McLemore 1982a). The best potential for uranium deposits in Precambrian rocks in New Mexico is in the Burro Mountains in Grant County (U.S. Department of Energy, 1980; O'Neill and Thiede, 1981). Additional favorable areas include the Sangre de Cristo Mountains, Tusas Mountains in Rio Arriba County, and Tajo granite in Socorro County. Other areas may also be favorable for uranium deposits. Some of these areas are described by McLemore (1982a).

Over 100 uranium and thorium occurrences are found in the Burro Mountains in western Grant County (Appendix 1). Three of these have produced 1,367 lbs (620 kg) U_3O_8 (Appendix 3). Most of the occurrences are in the White Signal, Black Hawk, Tyrone, and Telegraph districts. Radioactive pegmatites are also present in this area, especially in the White Signal and Gold Hills districts, and are discussed separately. Minor occurrences are also found in the Langford and Malone districts and throughout other parts of the Burro Mountains (Appendix 1). The Burro Mountains are highly mineralized and contain significant deposits of gold, silver, copper, lead, zinc, and fluorspar, but only copper has been produced recently.

The Burro Mountain consists of a Precambrian core overlain by Cretaceous and Tertiary sediments and Tertiary volcanics. Tertiary intrusives have been locally injected into the sequence. The Precambrian Bullard Peak and Ash Creek metamorphic series are intruded by the Burro Mountain granite (Precambrian) and basaltic to diabasic dikes (probably Precambrian). The majority of the mineral deposits occur in the Burro Mountain granite, except for mineralization at Tyrone, which occurs in the Tertiary Tyrone laccolith.

Uranium was first discovered in 1920 at the Merry Widow mine in the White Signal district (F. I. Leach, 1920). An unknown amount of radium was produced during the 1920's from the Floyd Collins, Merry Widow, and Eugenie mines, and about 500 lbs (227 kg) of torbernite were produced from the Eugenie mine (Gillerman, 1964). Only two mines produced uranium ore in the 1950's and early 1960's. Production from Floyd Collins amounted to 489 lbs (222 kg) of U_3O_8 at an average grade of 0.15% U_3O_8 and from the Inez property, 848 lbs (385 kg) of U_3O_8 at an average grade of 0.16% U_3O_8 (Appendix 3).

Several hundred veins occur in the White Signal district (Gillerman, 1964, 1968; Hedlund, 1978g, h), over 70 of which contain radioactive minerals (Fig. 27, Appendix 1). Most of the veins are small and rarely exceed 500 ft (152 m) in length. No veins have been explored at depths exceeding 206 ft (63 m; Gillerman, 1964, 1968). Four mineralogical types of veins can be distinguished: (1) quartz-pyrite veins, (2) quartz-specularite, (3) silver and silver-lead veins, and (4) turquoise veins (Gillerman, 1964, 1968). Uranium occurs in all four types; however, most of the larger deposits are associated with quartz-pyrite veins. Two major exceptions are the Apache Trail (quartz-specularite vein-deposit), and Uncle Sam (silver vein-deposit) deposits.

With a few exceptions, the uranium-bearing veins appear to occur at the intersection of east-trending quartz-pyrite veins and northwest-trending diabase dikes (Gillerman, 1964, 1968). The Floyd Collins and Inez deposits are associated with diabase dikes; however, gold-bearing quartz-pyrite veins are absent. The Blue Jay-Banner deposits occur within altered latite(?) dikes along a major east-trending fault (the Blue Jay fault). At the Blue Jay prospect, quartz-pyrite veins are absent; however, they are present farther to the west along the fault at the Banner prospect. The majority of the gold-producing veins contain uranium minerals or radiometric anomalies; however, only one silver vein, the Uncle Sam mine, contains uranium minerals. The turquoise veins contain only minor amounts of uranium.

Uranium mineralogy is complex and is described by Gillerman (1964, 1968). Uraninite is present, but the dominant ore minerals are secondary phosphates. Much of the phosphate is probably derived from phosphate-enriched diabase and latite dikes (Gillerman, 1968). A sample from the Merry Widow mine assayed 0.02% U_3O_8, and a sample from the Blue Jay mine assayed 0.036% U_3O_8, trace Au, and 0.5 oz/ton Ag (Appendix 2). Up to 0.59% U_3O_8 is reported from analyses by O'Neille and Thiede (1981).

The uranium-bearing veins are small and irregular, but many individual veins may occur along a single fault (Fig. 27). The age of mineralization is uncertain; field relationships tend to indicate a Tertiary age (Gillerman, 1964, 1968, 1970). The source of the uranium is unknown. The Tyrone laccolith, Tertiary volcanics, a buried pluton, and the Precambrian Burro Mountain granite could have contributed uranium (Gillerman, 1968; O'Neill and Thiede, 1981). This area is considered favorable for containing uranium deposits; however, additional drilling and geochemical studies are required to adequately assess the potential.

The Black Hawk mining district (or Bullard Peak district) is known for silver veins containing appreciable amounts of nickel, cobalt, and uranium. This unique mineral association is rare and is one of a few representatives of a native silver-nickel-cobalt-uraninite assemblage (Gillerman, 1964). Seven uranium occurrences in this area are described in Appendix 1, although none of these occurrences have produced any uranium ore.

The veins fill fractures and faults that trend northeasterly in the Burro Mountain granite and quartz diorite, and the Tertiary Twin Peaks monzonite porphyry stock. Uraninite is the dominant uranium mineral, although it is a minor constituent of these silver veins. Old records from the Alhambra and Black Hawk mines indicate that cobalt and nickel increase with depth. Uraninite is associated with the nickel and cobalt and may also increase with depth (Gillerman, 1964, 1968). The Black Hawk mine is the deepest mine in the district at 497 ft (151 m) (Appendix 1).

Fractures and faults are the primary ore controls. The veins are within 1,000 ft (305 m) of the Tertiary monzonite porphyry stock and the veins tend to thin when intruding monzonite porphyry dikes. The monzonite porphyry tends to concentrate mineralization on one side of the dike; however, the veins are thinner on the opposite side. When the veins occur along margins of monzonite porphyry dikes, they tend to thicken (Gillerman, 1964, 1968).

The uranium potential of this area is speculative. A dump sample from the Alhambra mine assayed 0.17% U_3O_8 (Appendix 2) and higher assays are reported (Gillerman, 1964, 1968, Gillerman and Whitebread, 1956). However, very little information on the depths of these veins is available. Drilling of this area is required to adequately assess the uranium, nickel, cobalt, and silver potential. Uranium could be mined as a co-product of the other metals.

The Tyrone copper deposit in the Burro Mountains contains anomalously large amounts of uranium (Raup, 1953). Torbernite and autunite occur in the kaolinized areas of the porphyry-type copper deposit (Kolessar, 1970, 1982). This copper deposit occurs in the Tyrone quartz monzonite laccolith (Tertiary) and the underlying Precambrian Burro Mountain granite. Copper mineralization, dominantly as chalcocite, varies from a few feet (m) to 300 ft (91 m) in thickness and is associated with sericitic alteration. Uranium occurs in highly fractured, kaolinized areas of the Tyrone laccolith and Precambrian granite (Appendix 1). This hydrothermal deposit has been classified as allogenic by O'Neill and Thiede (1981) based on (1) a Precambrian granitic source, (2) low thorium-to-uranium ratios, and (3) low thorium concentrations. However, in the vicinity of the Tyrone copper mine uranium is sporadic, discontinuous, and secondary, and does not constitute an economic by-product at the present time (Joseph Kolessar, pers. commun., 9/22/82). Uranium occurrences in the Copper Mountain area (Kolessar, 1970; Appendix 1) are also low-grade, discontinuous, and subeconomic.

The Wild Horse Mesa area is in the eastern part of the Telegraph district in the northern Burro Mountains, Grant County (Fig. 28). In this area, the Burro Mountain granite is unconformably overlain by the Beartooth Quartzite and Colorado Shale (Cretaceous). Although uranium has not been produced in this area, fluorite and base metals have been. Currently this area is inactive except for sporatic exploration for uranium and fluorite.

Uranium mineralization in this area occurs as (1) veins along faults, shears, and fractures within granite (Fig. 29), (2) veins along faults between the granite and Beartooth Quartzite, (3) veins and replacements of quartzite along the unconformity between the granite and Beartooth Quartzite, and (4) minor amounts within fluorite veins that intrude the granite (Appendix 1). The veins are thin and discontinuous and are associated with iron-staining, silicification, and sericitic alteration. Ten uranium occurrences are found in this area (Fig. 28) and numerous radiometric anomalies occur along the unconformity and major fault and shear zones. Chemical analyses of nine samples range from 0.009% to 0.59% U_3O_8 and trace amounts of gold may also occur (Appendix 2). The highest chemical uranium values are from a fault zone between granite and quartzite at the Union Hill claims (Fig. 30; Appendix 1). The samples were taken near the portal of a 180-ft (55 m) adit, which penetrates two shear zones (Fig. 30). Additional radiometric anomalies occur along the same fault.

This area is highly fractured and faulted. Four major fault systems which trend northeast, northwest, west, and north (O'Neill and Theide, 1981), appear to coincide with the uranium mineralization. The fluorspar veins trend northwest (Gillerman, 1964) and are slightly radioactive (Appendix 1). Tertiary rhyolites have intruded parts of the sequence, but are barren of mineralization. Two samples of rhyolite contain less than 5 ppm U (O'Neill and Theide, 1981).

Similar fault-controlled uranium occurrences are found in the Red Rock area (western Telegraph district) at the Purple Rock

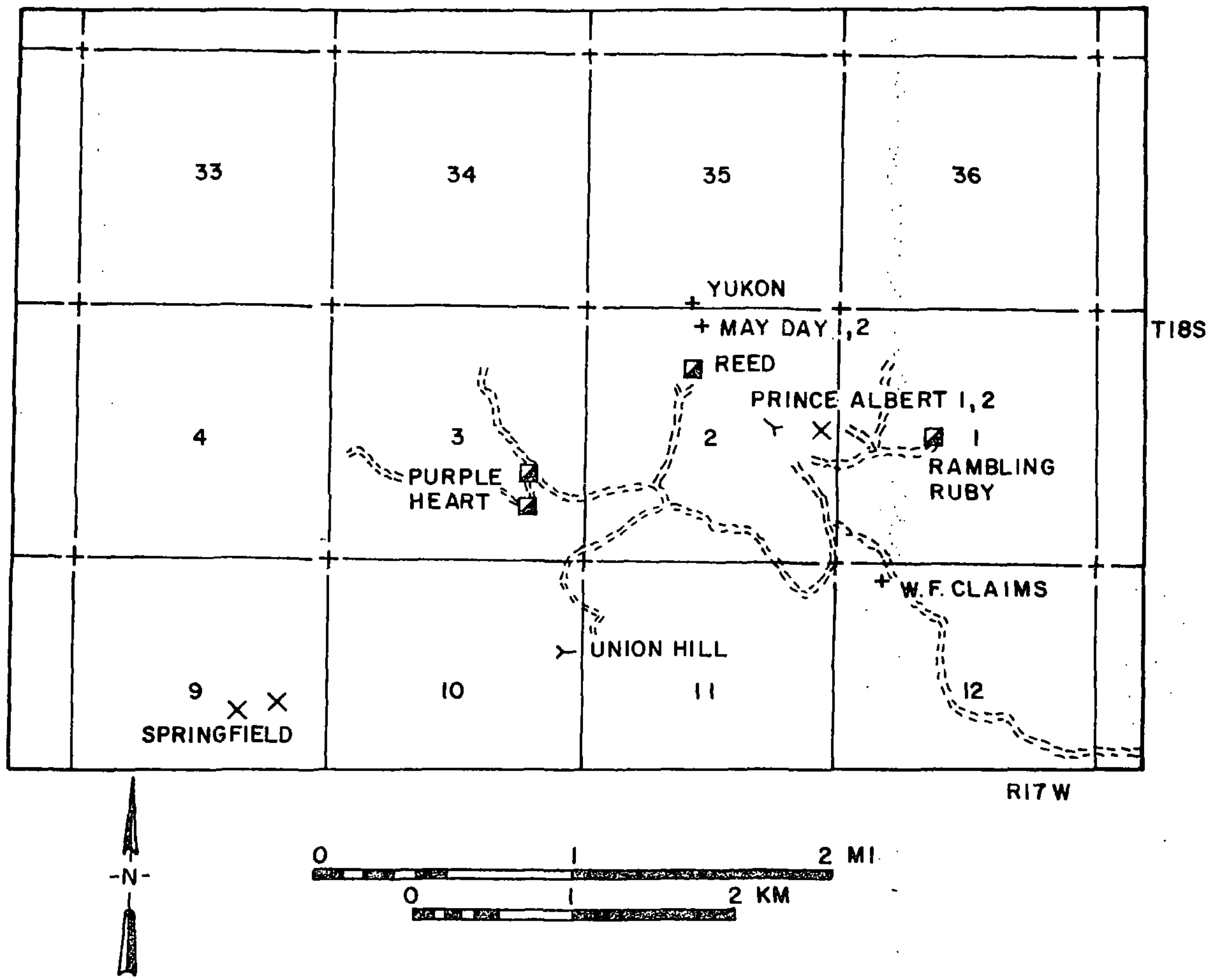
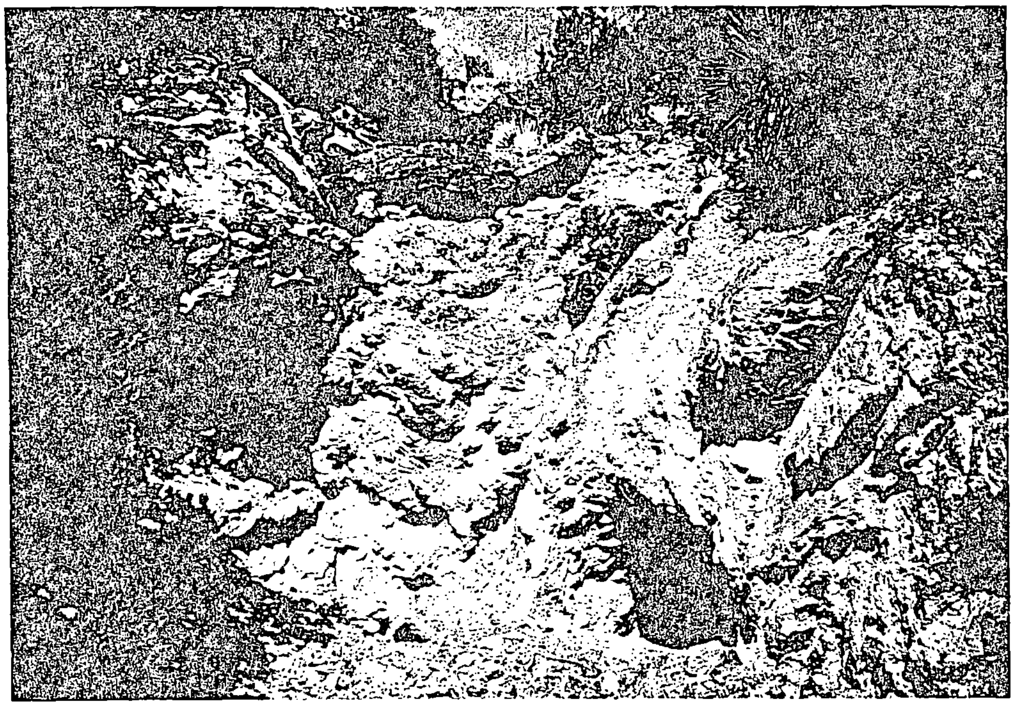


FIGURE 28-URANIUM OCCURRENCES IN THE WILD HORSE MESA AREA, GRANT COUNTY.

Figure 29 - Mineralized shear or fault zone at the Prince Albert #1 mine in the Wild Horse Mesa area, Burro Mountains, Grant County looking south. The adit is in Precambrian granite.



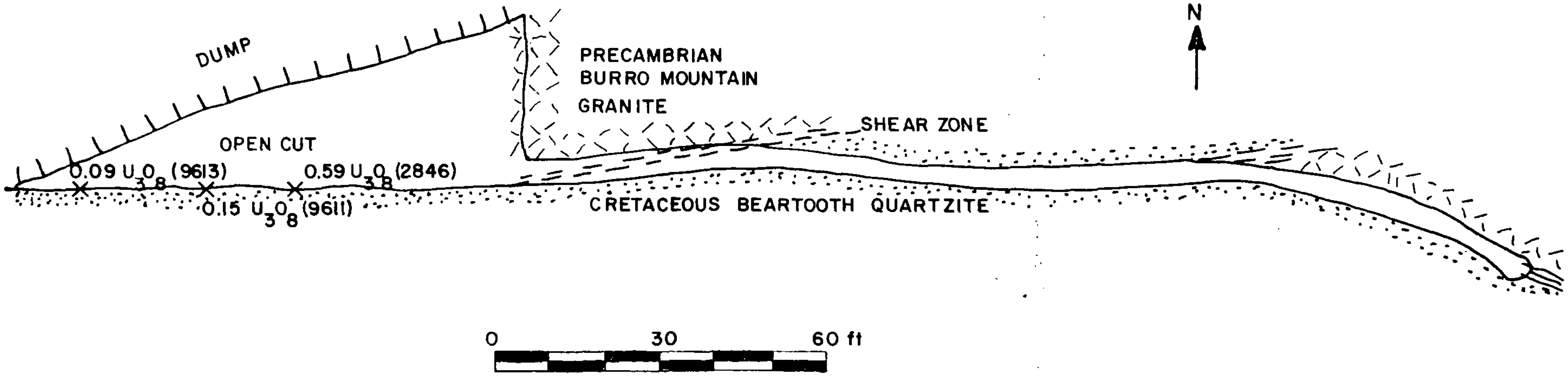


FIGURE 30-PLAN MAP OF THE UNION HILL ADIT (18S.17W.10.242), GRANT COUNTY, SHOWING LOCATION OF SAMPLES.

Mine, Blue Eagle, and Sandy Group; in the Little Burro Mountains district near Tyrone at the Tunoco mining claims (18S.15W.28.231,243, Appendix 1), Section 21 (18S.15W.21.211; Appendix 1); and in the Little Burro Mountains district (18S.15W.35.143; Appendix 1). At the Purple Rock mine and the Tunoco mining claims, uranium is associated with fluorite (Appendix 1). In the Little Burro Mountains district, uranium mineralization is associated with faults in granite and faults between the granite and Beartooth Quartzite. Chemical uranium values from these samples in this area range from 0.002 to 0.008% U_3O_8 (Appendix 2). Faults in Precambrian granite control uranium mineralization at the Purple Rock mine and the Tunoco mining claims as well. In 1956, 30 lbs (14 kg) of U_3O_8 at an average grade of 0.04% U_3O_8 were produced from Section 21 in the Little Burro Mountains district.

The age and origin of mineralization are unclear. Hewitt (1957, 1959) described at least two periods of fluorite deposition in the Redrock area. Deposition of colorless to green fluorite was followed by deposition of radioactive purple fluorite. Age of fluorite mineralization is interpreted to be mid- to late-Tertiary (Hewitt, 1959; Gillerman, 1964, 1968). However, most of the uranium mineralization in the Wild Horse Mesa is not associated with the fluorite veins, although fluorine may be anomalously high (O'Neill and Thiede, 1981). Elsewhere in the Burro Mountains uranium is interpreted as occurring after fluorite mineralization (Kolessar, 1970; Gillerman, 1964, 1968).

Additional minor and isolated uranium occurrences are found in the Burro Mountains (Appendix 1). Some of the occurrences are related to deposits within recognized mining districts. Other occurrences may be indicative of additional uranium deposits. Most of these occurrences are along fractures and faults that trend northeast, northwest, or east.

Detailed geological and geochemical studies are warranted in the Burro Mountains to adequately assess this area for mineral potential. In addition, these studies could address the source and genesis of the mineralization in the Burro Mountains, and also the relationship, if any, between the various mineralized areas.

Uranium occurrences are found scattered throughout the Sangre de Cristo Mountains in northern New Mexico (Appendix 1; McLemore, 1982a). Many of these areas have not been mapped in detail, and any interpretation of the uranium potential thus is difficult. Follow-up studies are warranted in several areas where radiometric anomalies were detected by stream-sediment sampling and aerial reconaissance surveys.

The only recorded uranium production from the Sangre de Cristo Mountains other than from pegmatites was a 5-ton (4.5 metric ton) ore shipment at 0.03% U_3O_8 from the Black Copper #2 Mine in Taos County in 1957 (Appendix 3). Uranium mineralization was found in two 6-ft (2 m) wide zones of gold-silver veins about 50 ft (15 m) apart. The mineralization occurs in Precambrian granodiorite near a major fault (Condie, 1981; S. D. Brown, 1982). Field examination of the immediate surface area adjacent to the mine could not locate any significant radioactivity (Appendix 1); however, uranium mineralization may occur at depth.

The Bitter Creek prospects are located along Bitter Creek about three mi (five km) north of Red River in the Anchor district. Several caved adits and prospect pits are located along shear zones and pegmatites; most of them are along silver-bearing quartz veins (J. H. Schilling, 1960).

The Bitter Creek area is in the vicinity of the Questa caldera margin (currently being mapped by the U.S. Geological Survey). This area is highly faulted and fractured. A block of granitic and gneissic rocks is faulted into the Tertiary volcanics (Condie, 1981). Uranium mineralization occurs along faults, shear-zones, and pegmatites within the Precambrian fault block (Fig. 31). One sample from a shear zone in coarse-grained granite assayed 0.03% U_3O_8 and 16 ppm Th (#1786, Appendix 2); whereas a sample from a pegmatitic granite assayed 0.11% U3O8 and 47 ppm Th (#1787, Appendix 2). The Precambrian rocks are a complex of granite, gneiss, diabase dikes, and pegmatites. Additional mapping is required to determine the extent and origin of the uranium mineralization.

Six uranium occurrences are found in the Costilla Peak massif in northern Taos County (Appendix 1), and additional stream-sediment samples contain greater than 5,000 ppm U_3O_8 (Fig. 32; Reid and others, 1980b; Goodknight and Dexter, 1983). Stream and spring waters in this area contain as much as 250 ppb U_3O_8 (Reid and others, 1980b; Morgan and Broxton, 1978). Three types of Precambrian granite are found in the Costilla Peak massif: a coarse-grained biotitic granite, a pegmatitic granite, and a foliated gneissic granite. Pegmatites in the vicinity of the Billy Goat prospect are radioactive (Fig. 32; Appendix 1); a

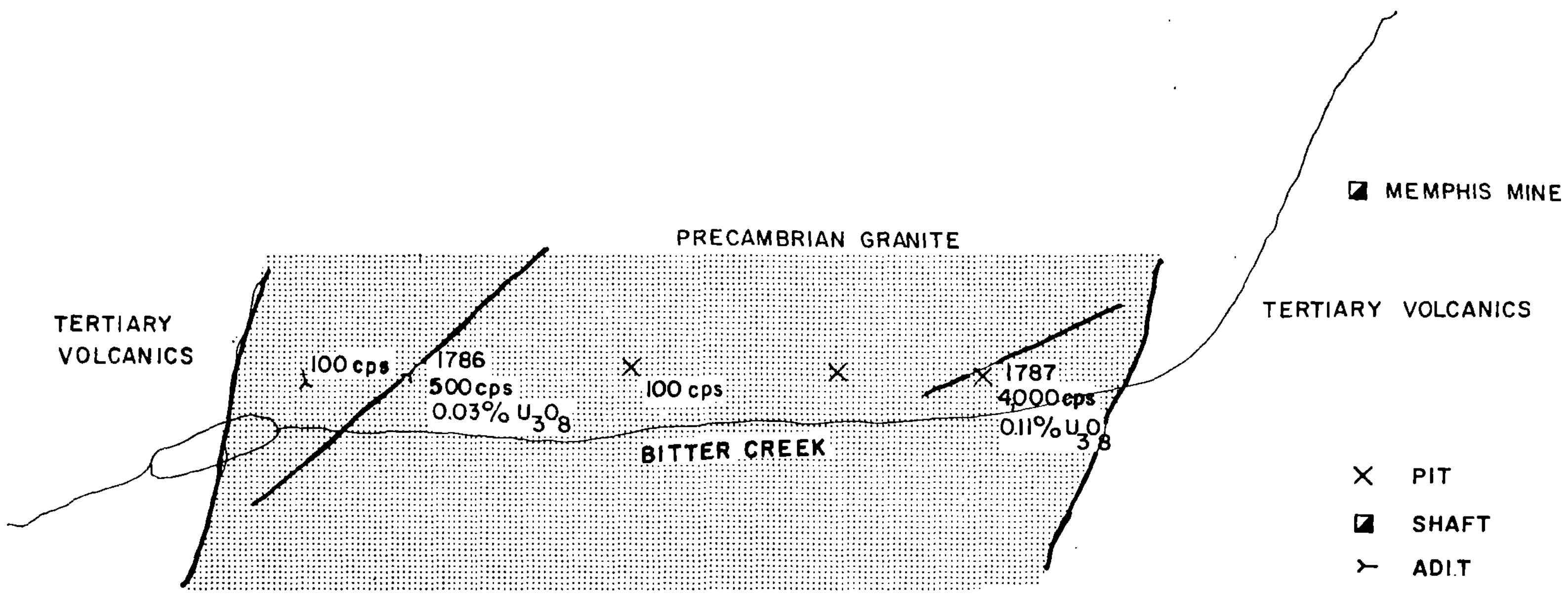


FIGURE 31 - BITTER CREEK PROSPECTS AND MINES, NORTH OF RED RIVER, TAOS COUNTY, NEW MEXICO.

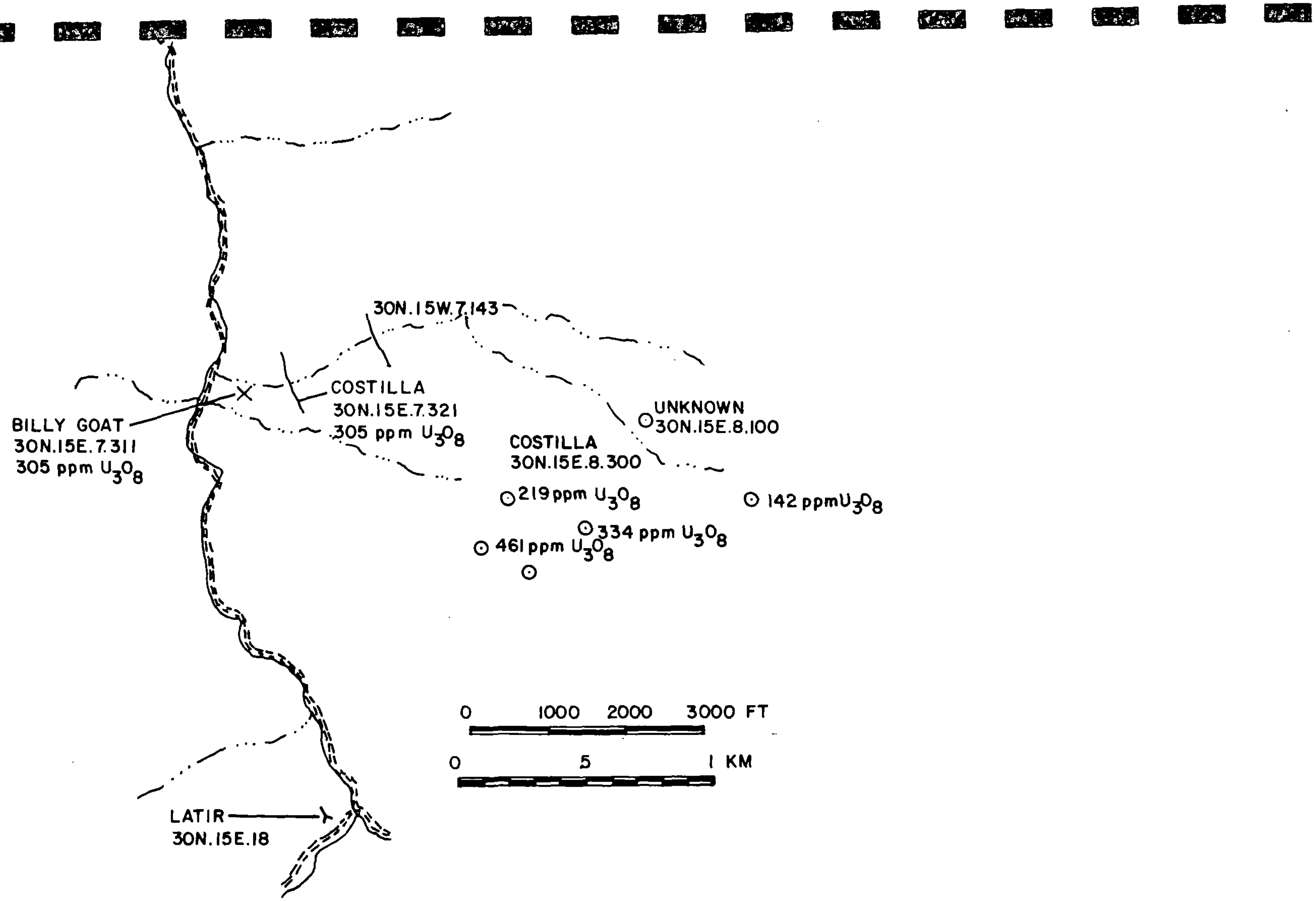


FIGURE 32-URANIUM OCCURRENCES IN THE COSTILLA PEAK MASSIF, TAOS COUNTY. CHEMICAL ANALYSES FROM REID AND OTHERS (1980a).

sample from a radioactive pegmatite contained 305 ppm U_3O_8 (Reid and others, 1980b). Additional granitic samples collected by Goodknight and Dexter (1983) contain up to 0.38% U_3O_8. Uranium mineralization is fault-controlled and is found along north-south trending fractures in coarse-grained granite. Uranosilicates, dominantly uranophane, are common in many mineralized samples (Goodknight and Dexter, 1983). No other mineralization is found in the area, although anomalously high concentrations of copper, lead, and zinc are reported at one locality by Goodknight and Dexter (1983).

The Costilla Peak granite is anomalously high in uranium (Goodknight and Dexter, 1983), indicating a potential source. Furthermore, the granite may have been covered by Tertiary volcanics of the Amalia Tuff, which could have released uranium into the system (Goodknight and Dexter, 1983). Detailed mapping and geochemical surveys are required in this area, especially at the higher elevations, to adequately assess the uranium potential.

Anomalously high uranium values in stream sediments and water samples north and east of Big Costilla Peak may indicate additional uranium occurrences in that area (Morgan and Broxton, 1973; Goodknight and Dexter, 1983). Numerous uranium anomalies from the aerial radiometric survey of the Raton 1- by 2-degree quadrangle further suggest the presence of uranium occurrences in the Big Costilla Peak area of the Costilla Peak massif (Geometrics, 1979; Goodknight and Dexter, 1983).

A Precambrian granite similar to the Costilla Peak massif occurs southwest of Costilla Peak in the Urraca Canyon and Rito del Medio in Taos County. Stream-sediment samples contain up to 383 ppm U_3O_8 in Urraca Canyon and up to 30 ppm U_3O_8 in Rito del Medio. Uranium concentration appears to increase with increase in elevation (Reid and others, 1980b), suggesting that the uraniferous source is at higher elevations.

Only one unverified uranium occurrence is found in the Rio Hondo area, Taos County (Appendix 1); the exact location is unknown. Stream-sediment samples in the Rio Hondo area contain up to 159 ppm U_3O_8, but rock samples collected at the bottom of the canyon contained less than 4 ppm U_3O_8 (Reid and others, 1980b). Additional geochemical sampling of the higher elevations is warranted.

Several uranium occurrences are associated with fluorite in the Tusas Mountains, Rio Arriba County (Fig. 33, Appendix 1). Uranium occurs in the Precambrian Tusas Mountain granite (1) at the contact between the granite and Precambrian Moppin Formation, (2) along the boundaries of inclusions, xenoliths, and roof pendants, and (3) along fractures within the granite. The Tusas Mountain granite is white to pink, fine-grained, porphyritic, and only locally foliated (Wobus and Hedge, 1982; Kent, 1980). The intrusive contact with the Moppin Formation is sharp and well exposed along the west edge of the intrusive. The distinctive features of this granite are the lack of pervasive foliation and its younger age as compared with other Precambrian granites in northern New Mexico. The Tusas Mountain granite is between 1,430 and 1,500 m.y. old, as compared to 1,700 m.y. old foliated granites in the Tusas Mountains (Wobus and Hedge, 1982). The

Tusas Mountain granite (Wobus and Hedge, 1982) is similar in its chemistry to the high Si and high K granites of Condie and Budding (1979).

In 1954, 6 lbs (3 kg) of U_3O_8 of an average grade of Ø.Ø4% U_3O_8 were produced from the Tusas East Slope #5 prospect. One 5-ton (5-metric ton) shipment from the Tusas East Slope Claim assayed Ø.12% U_3O_8. A second ore shipment from the JOL prospect in 1956 amounted to 6 lbs (3 kg) of U_3O_8 at an average grade of Ø.Ø4% U_3O_8 (Appendix 3). However, chemical analyses of samples collected by Craig Goodknight and Jim Dexter (Bendix Field Engineering Corp.) contained up to Ø.17% U and 2% Th (28N.7E.13.333; Fig. 33, Appendix 1). Anomalous amounts of Nb (72Ø ppm in #MFQ-8Ø6, Fig. 33) and La (58Ø ppm, 28N.7E.24.223, Fig. 33, Appendix 1) are present in some of the samples. An open-file report in 1983 by Craig Goodknight and Jim Dexter interprets and classifies the uranium occurrences associated with the Tusas Mountain granite.

Uranium occurs along fractures and joints in weathered and altered Precambrian Tajo granite in the Rio Grande valley, east of Socorro (McLemore, 1983b; Appendix 1). Six outliers of granite are exposed along two northwest-trending fault zones (Fig. 34). Fluorite and barite veins occur along these faults, but only the Gonzales fluorite-barite prospect is radioactive, indicating the presence of uranium and thorium. Several radiometric anomalies occur along northwest- to northeast-trending faults, fractures, and joints within five of the six outliers (Fig. 34). Purple fluorite, hematitization, and silicification are associated with uranium mineralization.

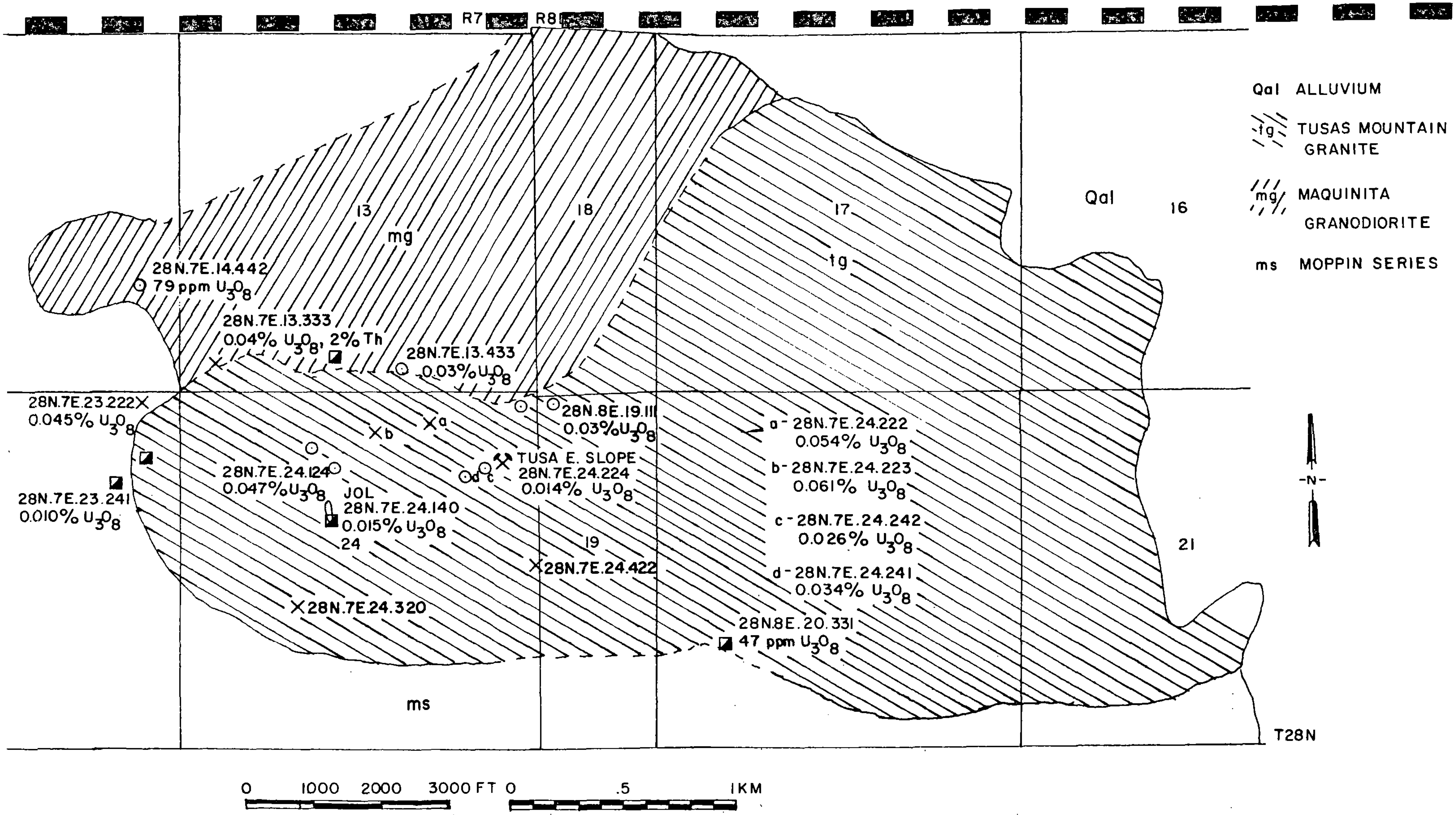


FIGURE 33- URANIUM MINES AND OCCURRENCES IN THE TUSAS MOUNTAINS, RIO ARRIBA COUNTY. CHEMICAL ANALYSES FROM CRAIG GOODKNIGHT AND JIM DEXTER (BENDEX FIELD ENGINEERING CORP.) AND NMBMMR CHEMICAL LABORATORY (APPENDIX 2.)

Although no uranium minerals have been identified, uranium concentrations are as high as 0.019% U_3O_8 (Appendix 2). Higher uranium concentrations are expected to occur at depth, below the zone of oxidation. Lead concentration in one sample is 0.13% (Appendix 2).

The uranium potential of the Tajo granite is uncertain. Although this granite exhibits the mineralogy and alteration typical of uraniferous granitic rocks, the low grade and small size of known surface mineralization suggests a poor economic potential. However, the subsurface extent of the Tajo granite is not known. The area is within the Rio Grande graben and is extremely faulted. It is conceivable that the unexposed portion of the Tajo granite lies at great depth.

Uranium in Tertiary intrusive and volcanic rocks

Many uranium and thorium occurrences are found in Tertiary intrusive and volcanic rocks in New Mexico and most are described under deposits in copper or fluorite veins, or thorium deposits in veins. However, a few uranium occurrences are found as hydrothemal-vein deposits in these rocks. Some of these occurrences may actually be volcanogenic uranium deposits, but are described here as hydrothermal-vein deposits. In New Mexico, uranium occurrences in these Tertiary rocks are found in sulfide veins, copper veins, iron deposits, and fluorite veins. Only two areas in the state, the Baby mine in Catron County and La Bajada mine in Santa Fe County, produced uranium from vein deposits.

Several occurrences are found in the Mogollon volcanic field

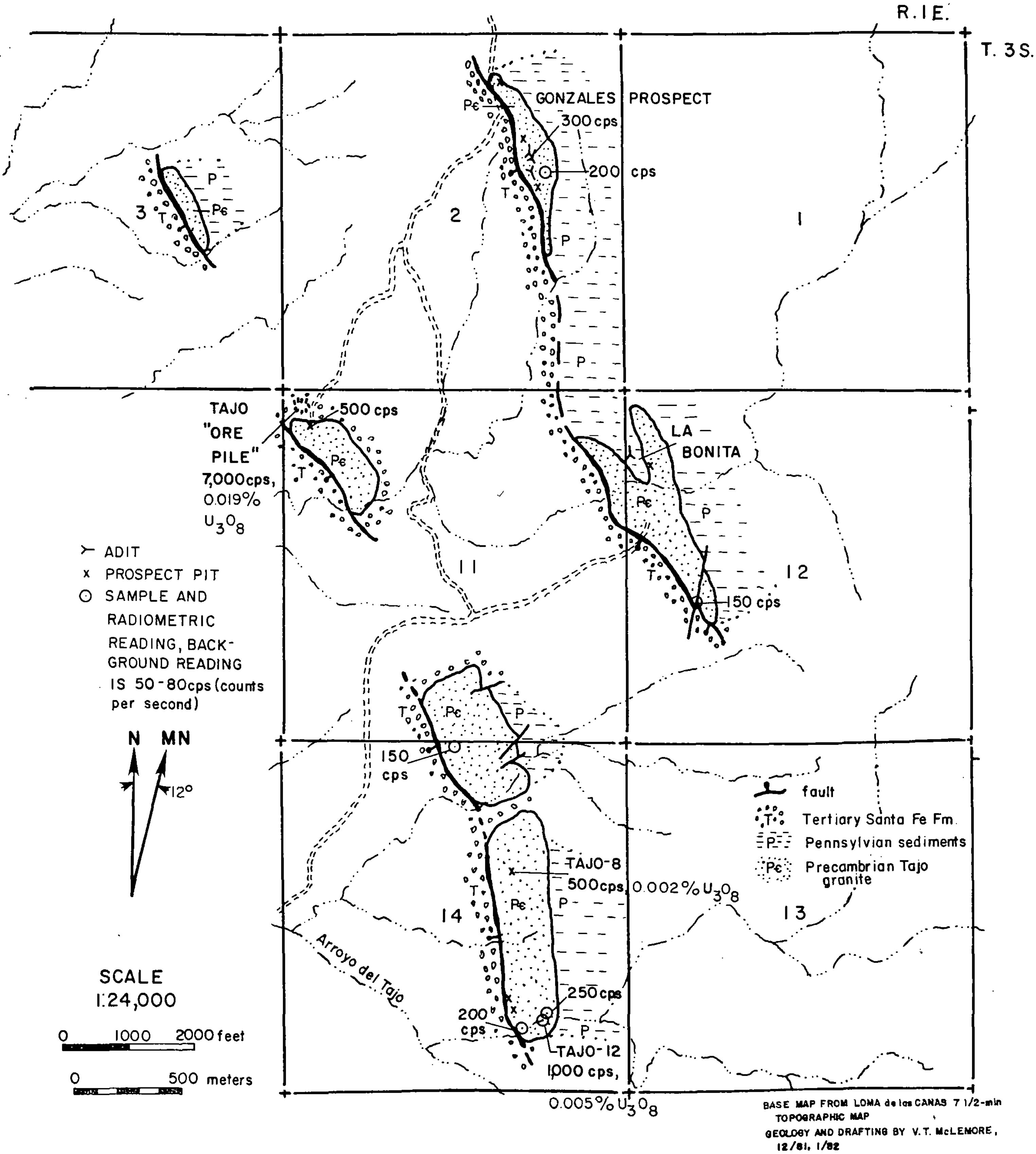


FIGURE 34 - Geologic map showing anomalously high radiometric readings of the Tajo granite (Precambrian), Socorro County, New Mexico.

in southwestern New Mexico (Appendix 1; McLemore, 1982a); however only one deposit yielded any ore, the Baby mine in the Mogollon Mountains in Catron County. Uranium production from this mine amounts to 14 lbs (6 kg) of U_3O_8 at an average grade of 0.01% U_3O_8 (Appendix 3). One additional uranium occurrence is found in the area, the Evelyn prospect, located south of the Baby mine in Whitewater Canyon (Appendix 1).

Both of these uranium occurrences are in a highly mineralized area in the Mogollon mining district. Gold, silver, fluorite, copper, lead, and uranium have been produced from the district (Ratte and others, 1979; Collins, 1957). The area is located on the northwestern edge of the Bursum caldera (Ratte and others, 1979; New Mexico Geological Society, 1982) and the resulting fracturing and faulting has controlled mineralization. Uranium and other mineralization occur along north-northeast and west-northwest trending faults in the precaldera Whitewater Creek Rhyolite and may be related to the caldera. Uranium and vanadium minerals are associated with pyrite and fluorite in a Last Chance Andesite dike trending N 70° W and along the extension of a northwest-trending fault. The sulfide-bearing quartz veins, common to other areas of this district, are absent at the Baby mine.

Mineralization at the Evelyn prospect occurs in clay gangue along northeast-trending shears in Whitewater Creek Rhyolite (Collins, 1957). Sulphide-bearing quartz veins are absent at the Evelyn prospect and uranium is associated with pyrite.

The uranium potential in the rugged Mogollon Mountains is speculative. An aerial radiometric anomaly coincides with this area (White and Foster, 1981; Texas Instruments, Inc., 1978); however, a reconnaissance of faults and veins in the area by Collins (1957) failed to locate any additional uranium mineralization on the surface. The author's field reconnaissance in the area was also unsuccessful. Two areas were found by Collins (1957) that were similar in alteration and mineralogy to the Baby mine area; but no anomalous radioactivity could be detected. Furthermore, the steep sided canyons and rugged terrain in the Mogollon Mountains would hamper exploration and mining efforts.

The La Bajada mine is located in the canyon of the Santa Fe River, south of Santa Fe (Appendix 1). A small amount of copper and silver was produced in the 1920's (Chenoweth, 1979) and 27,111 lbs (12,297 kg) of U_3O_8 at an average grade of 0.14% U_3O_8 from 1956 to 1966 (Appendix 3). The first two shipments in 1956 and 1957 averaged over 0.18% U_3O_8. In addition to uranium, copper, and silver mineralization, cobalt, nickel, molybdenum, and germanium are present in significant concentrations (Chenoweth, 1979; Hilpert, 1969). Mineralization occurs in thin veins along a fault zone within the Oligocene Espinaso Formation and a limbergite dike. The uniqueness of the deposit is due to the presence of ore-controlling organic material, yet the volcanics and limburgite dike are intensely altered by hydrothermal solutions. The organic material is thought to have been derived from the underlying Cretaceous sediments (Haji-Vassiliou and Kerr, 1972, 1973). Due to the complex association of uranium and organic material, uranium minerals have not been identified (Hilpert, 1969; Lustig, 1958). A sample from the dump contains 0.09% U_3O_8, 1.51% Cu, and 19 ppm Th (Appendix 2).

The Lone Star Mining Company produced uranium from the 200-ft (61 m) long, 50-ft (15 m) wide, and 200-ft (181 m) deep open pit. The pit was stripped over most of the underground workings. Environmental problems prevented development and re-opening of the mine in the 1970's. In late 1970's, Bokum Resources and Union Carbide Corp. drilled exploratory holes in the vicinity of the La Bajada mine; however, their results are not available. Reserves are probably present at the mine, but environmental problems will hamper future mining of this hydrothermal deposit. One additional occurrence, the Hiser Moore #1, is found in the area.

Uranium occurs along fractures and shear zones in many areas. At the Mimi #4 claim in Sandoval County, 0.018% U and 171 ppm Th (Appendix 2) occurs in hematitic altered latite dikes and sills (Fig. 35). Uranium roll-type deposits also occur in the Galisteo Formation elsewhere in this area (McLemore, 1982c). Uranium veins are found at Cerro Colorado, Bernalillo County, and Black Butte, Socorro County. Uranium concentration at Cerro Colorado is 0.007% U_3O_8 (Appendix 2). Uranium occurs along a fault zone at the Mule Creek prospect and is in the vicinity of the Mule Creek cauldron (New Mexico Geological Society, 1982). Additional similar occurrences are present in the state (Appendix 1). Some of these occurrences are high grade (Mule Creek prospect); however, uranium mineralization is discontinuous and spotty. Most of these occurrences may be indicative of uraniferous sources nearby.

Figure 35 - Uranium mineralization occurs along fractures in latite dike at the Mimi #4 claim in Sandoval County and is typical of many deposits in igneous rocks

Uranium in copper veins

Numerous areas in Taos, Rio Arriba, Santa Fe, Cibola, Lincoln, Otero, and Luna Counties are characterized by copper and uranium minerals that occur along shear zones, fractures, and in veins (Appendix 1). Uranium and copper in most of these areas tends to be low grade and low tonnage. They are found in highly altered and mineralized areas and may be associated with silicification, hematization, and argillization.

Uranium and copper mineralization in the Picuris district, Taos County, and Petaca district, Rio Arriba County, occurs in veins and along fractures in Precambrian metamorphic rocks adjacent to or within pegmatites. Uranium and copper minerals also parallel schiltosity and foliation in the Picuris district. Up to 169 ppm U and 4.6% Cu are reported form samples at Copper Hill (Appendix 1; Craig Goodknight, Bendix Field Engineering Corp. written commun., 4/24/82). A sample from the Lucky Seven claim in the Petaca district contained 0.021% U_3O_8 (Appendix 1; U.S. Atomic Energy Commission, 1970), whereas samples from the Rancho AAA claim assayed 0.010% U_3O_8 and 3.00% Cu (Appendix 2).

In the Cerrillos and Nambe districts in Santa Fe County uranium occurs with copper, lead, and zinc deposits in Tertiary monzonite or monzonite porphyry. Samples from the Cash Entry, Evelyn Copper, and Turquoise mines in the Cerrillos district contained less than 0.001% U, but one sample from the Turquoise Hill mine contains 0.0085% U (Griggs, 1953). Low-grade uranium and copper mineralization at the Marion and Shaw #2 mines in the Nambe district occurs in Precambrian schists and granites

(Appendix 1).

The copper and uranium mineralization in the Permian Abo Formation in the Zuni Mountains has been discussed above. In addition to sandstone deposits, copper and uranium occur along shear-zones, fractures, and foliation planes within Precambrian granitic rocks near Diener (Fig. 23). Fluorite and barite may locally occur in these deposits.

Uranium and copper mineralization is found in the Nogal and Gallinas Mountains districts in Lincoln County (Appendix 1). Uranium, copper, and gold occur at the Silver Plume mine in the Nogal district, and uranium may occur elsewhere in the area. Uranium and thorium is associated with the copper-fluorite-bastnaesite deposits in the Gallinas Mountains.

Uranium and copper are present in Tertiary volcanic and intrusive rocks at Orogrande in Otero County, and Carrizalillo Hills, Cooks Peak, and Tres Hermanos Mountains in Luna County. The mineralization occurs along fractures and faults. A sample from the Calumet mine in the Carrizalillo Hills contains 0.003% U_3O_8 and 2.3% Cu (Appendix 2).

Minor copper and uranium occurrences are found along the Rio Grande valley in Socorro and Sierra Counties (Appendix 1; McLemore, 1983b). Copper and uranium minerals occur along foliation planes and fractures in Precambrian rocks and Tertiary volcanic rocks. Uranium concentrations are below economic grades, and silicification and hydrothermal-alteration are minor.

At the Glory No. 2 and Empire Group in the Iron Mountain district, Sierra County, uranium and copper occur in silicified sandstones and siltstones of the Abo formation and Tertiary rhyolite dikes. In 1955-1956, 10 tons of ore were produced yielding 38 lbs (17 kg) of U_3O_8 at an average grade of 0.18% U_3O_8 (Appendix 3). Uranium and copper minerals occur as disseminations, veinlets, and small pods in at least four horizons. Both uranium and copper are sporadically distributed and discontinuous in siltstones, sandstones, and rhyolites (Boyd, 1957). Mineralization is associated with silicification and argillic alteration, and was probably emplaced after or during intrusion of the rhyolites. The hydrothermal fluids moved through permeable siltstones and sandstones, and deposited uranium near accumulations of organic material. It is conceivable that uranium and copper mineralization pre-existed in the sandstones and siltstones, and was subsequently remobilized by hydrothermal solutions.

It is unlikely that any of these uranium and copper hydrothermal-vein deposits represent economic deposits, because they are small and low grade. However, many of these occurrences are indicative of uraniferous sources and perhaps may be indicative of uranium ore bodies in sandstones or igneous rocks in these terrains.

Uranium in Fluorite veins

Uranium occurs with many of the fluorite veins in central and southwestern New Mexico (Appendix 1; McAnulty, 1978). Generally, uranium occurs in trace amounts with purple to purple-black fluorite. Minor occurrences are found at the following localities: (1) the Mirabel mine in the Zuni Mountains, Cibola

County (Fig. 23); (2) in the fluorite-bastnaesite veins in the Gallinas Mountains, Lincoln County; (3) Juan Torres prospect in the Ladron Mountains, Socorro County; (4) Gonzales and La Bonita prospects, Socorro County; (5) Lyda K mine in the Caballo Mountains, Sierra County; (6) Blue Star prospect, Dona Ana County; (7) Lookout prospect and other fluorite veins in the Cooke's Range, Luna County; and (8) the Clum, Aquilar, Hines, Last Chance, Big Chief, Reed, Purple Rock, and Purple Heart mines in Grant County. Uranium production from the Blue Star prospect, Dona Ana County, amounted to 14 lbs (6 kg) of U_3O_8 at 0.06% U_3O_8; no other deposits have yielded uranium ore (Appendix 3).

Fluorite is common to many uranium deposits; however, most fluorite veins do not contain uranium in appreciable amounts. Uranium concentrations are typically less than 0.1% U_3O_8 (Appendix 1, 2). It is doubtful that uranium in fluorite veins in New Mexico would have any economic potential, although fluorite is common as a gangue mineral in uranium deposits.

Uranium deposits in altered or metamorphosed sediments

A few uranium occurrences are found in altered or metamorphosed sedimentary rocks near or adjacent to Tertiary igneous intrusives and occur as hydrothermal-vein, anatectic, or contact-metasomatic deposits (Appendix 1). These occurrences are isolated, small in size, and low grade. The subsurface potential has rarely been examined. These occurrences may be indicative of other types of uranium deposits, or of a uraniferous source.

Yellow uranium minerals were reported to occur along fractures in limestones and shales of the Chinle Formation near igneous dikes and sills at the Sonora prospect, Cibola County (Appendix 1; Hilpert, 1969; McLemore, 1982c). Copper, lead, silver and nickel minerals are present (Hilpert, 1969). Mineralization is within ten ft (3 m) of the igneous dikes or sills, but not all of the intrusives are mineralized.

At least 15 pyrometasomatic iron deposits in Lincoln County contain uranium mineralization (Appendix 1). Most of them are small replacement bodies within a few hundred feet of an intrusive igneous body (V. C. Kelley, 1949; Soulè, 1947; Sheridan, 1947; Griswold, 1959, 1964). The iron deposits have replaced limestones of the Permian San Andres and Yeso Formations, where these rocks have been folded. The primary minerals are magnetite and hematite, but secondary uranium minerals have also been identified (Walker and Osterwald, 1956; R. Weber, New Mexico Bureau of Mines and Mineral Resources, pers. commun., 1980). Most of the iron deposits are only slightly radioactive and uranium has not been produced from any of them (Appendix 1). Samples from the Eagle Nest #1 and 2, White Oaks district, and the American, Gallinas Mountains district, contained 0.01% or less U_3O_8 (Appendix 2). Iron deposits in the Orogrande district in Otero County are similar to the Lincoln County deposits, but are not radioactive (author's field notes, 11/14/82). Uranium potential in these deposits is poor.

The Napane claims are located in the Fremont mining district in the Sierra Rica, Hidalgo County (Fig. 1). Uranium production from this property amounts to 5 lbs (16 kg) U308 at an average grade of 0.19% U_3O_8 (Appendix 3). In addition, unknown quantities of copper, lead, zinc, and silver have been produced. Copper, lead, zinc, and silver mineralization was discovered in the area in 1884; uranium was discovered in 1953.

Mineralization is accompanied by silicification and recrystallization of the limestones and sandstones. Copper, lead, zinc, and silver veins and replacement pods are common throughout the Sierra Rica. However, uranium mineralization occurs only at the east end of the Napane claims (Fig. 36). Uranium minerals occur as disseminations within silicified sandstones and limestones, and along east-west trending fractures and joint surfaces. A sample from an ore dump contains 0.13% U_3O_8 and 1,276 ppm Th (Appendix 2). Chemical analyses up to 0.47% U_3O_8 are reported (May and others, 1981). Uranium mineralization is sporadic and discontinuous, and no other radiometric anomalies can be found in the area (personal reconnaissance, 12/2/81; May and others, 1981).

The potential of this area is unknown. Surface reconnaissance is unfavorable; however, no drilling for uranium has ever taken place. Two potential sources for uranium mineralization exist: the Apache cauldera and Tertiary granitic intrusives. Subsurface studies are needed to adequately assess the uranium potential. Potential for copper, lead, zinc, and silver is fair.

Thorium deposits in vein-type occurrences

Thorium veins constitute the largest reserves of relatively high-grade thorium in the United States. The reserves in veins

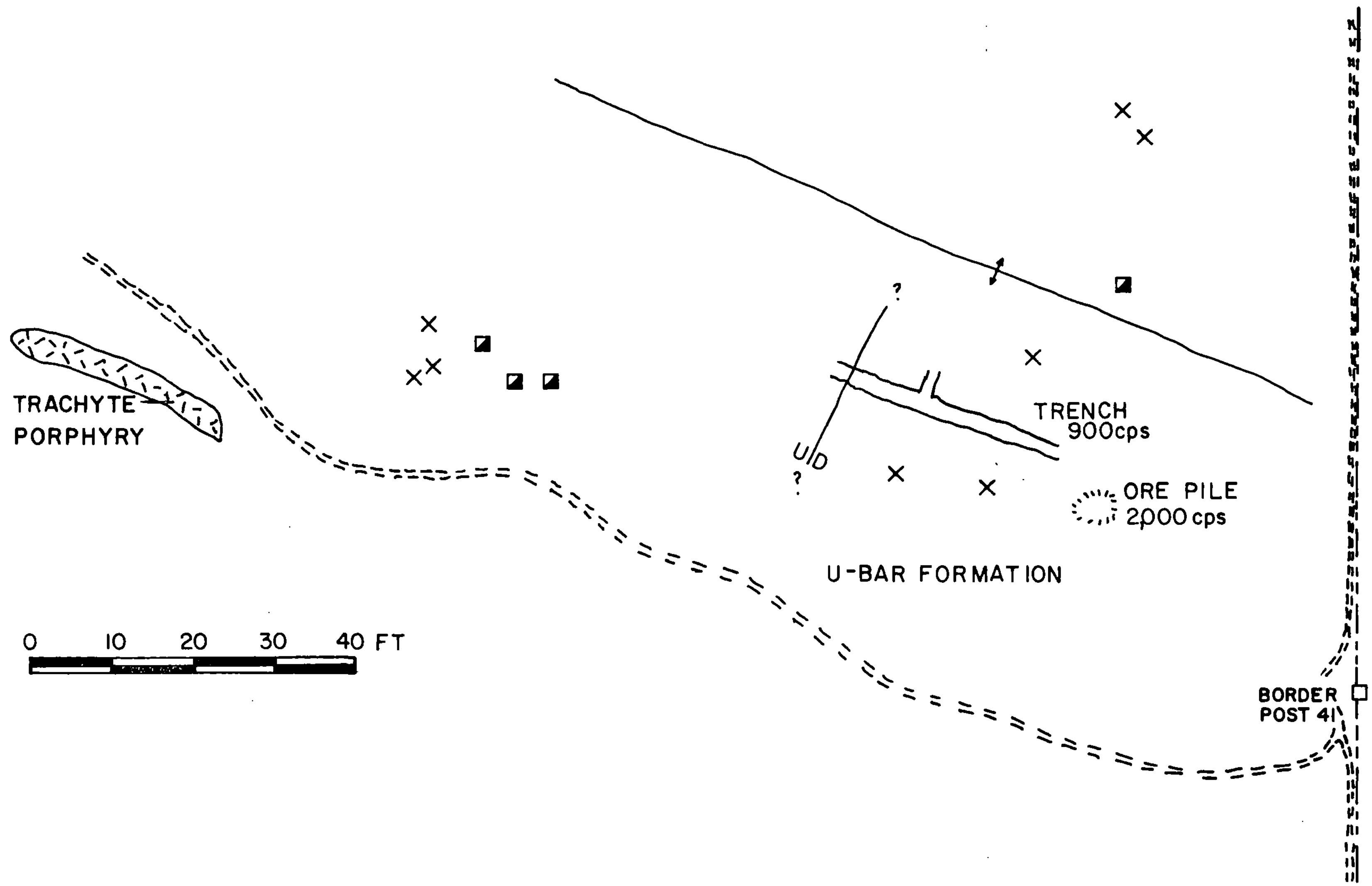


FIGURE 36-MAP OF THE NAPANE CLAIMS, HIDALGO COUNTY. MODIFIED FROM STRONGIN (1957).

are estimated as 142,000 tons (128,820 metric tons), about 75% of the total thorium reserves in the United States (Staatz and others, 1979). Most of the reserves are from seven areas in Colorado, Idaho, Montana, Wyoming, and California, and most of these veins are associated with alkalic igneous rocks or carbonatites (Staatz, 1974; Staatz and others, 1979). Unfortunately, thorium veins in New Mexico have not been adequately evaluated.

Several areas in New Mexico are known for their thorium occurrences (Fig. 3). Vein-type deposits in igneous and metamorphic rocks containing thorium and minor amounts of uranium occur in the Chico Hills area, Colfax County; Gallinas and Capitan Mountains, Lincoln County; Caballo Mountains, Sierra County; Burro Mountains, Grant County; and Cornudas Mountains, Otero County (Appendix 1). Additional thorium occurrences are found in pegmatites and carbonatites; these deposits are discussed separately. In addition, the beach-placer sandstone deposits in northern New Mexico contain thorium (discussed above).

Although none of these vein-deposits have been mined specifically for thorium, bastnaesite was produced from the Red Cloud and Rio Tinto mines in the Gallinas Mountains, Lincoln County (Appendix 1). Three tons (3 metric tons) of ore yielding one lb (0.5 kg) of U_3O_8 (0.02% U_3O_8) was produced from the Bear Canyon Group in the Capitan Mountains, Lincoln County (Appendix 3); the thorium content is unknown.

Thorium-bearing veins in New Mexico, as elsewhere in the

United States, occur as tabular bodies, narrow lenses, breccia-fillings. They vary from a few feet to 1,000 ft (305 m) in length and from a fraction of an inch to 10 ft (3 m) in width. Thorium, uranium, and rare-earth elements in these veins tend to be spotty, disontinuous, and low-grade; unlike other thorium-vein deposits in the country (Staatz, 1974). Thorium veins in the Chico Hills area, Gallinas Mountains, Caballo Mountains, and Cornulas Mountains are associated with alkalic igneous rocks similar to many thorium-vein deposits in Colorado, Idaho, Montana, and California (Staatz, 1974). Thorium potential exists in New Mexico; however, the lack of demand for thorium has prevented adequate exploration and development of potential areas in the state.

Twenty-three samples collected during field reconnaissance were assayed for thorium (Appendix 2). The highest concentrations are of pegmatite and beach-placer sandstone samples. The thorium content of carbonatite and thorium-vein samples were low; however, higher concentrations can be expected at depth.

The Chico Hills area is located in eastern Colfax County south of the Raton-Clayton volcanic field. Although only six occurrences are described in Appendix 1 (Fig. 5), Staatz (1982) located 29 thorium veins in a 16 mi^2 (41 km^2) area in the vicinity of Laughlin Peak. The veins are up to 800 ft (244 m) long and up to 20 ft (6 m) thick, and intrude Cretaceous sediments, Tertiary volcanic flows, and Tertiary intrusive dikes and sills. The veins appear to be associated with alkalic intrusive dikes and sills (Staatz, 1974; 1982). Samples of these thorium veins collected by Staatz (1974) range from less than 0.05% up to 0.82% Th. Additional samples collected by Reid and others (1980a; #428, 866-869) as part of the NURE program contained up to 278 ppm U, 150 ppm Nb, and greater than 1,000 ppm La. Thorium was not looked for; however, it is probable that these samples contain anomalous amounts of thorium because they are quite radioactive but contain very little uranium (Reid and others, 1980a; #866, 867). Thorite, brookite, xenotime, and florencite are reported to occur in some of the thorium veins; quartz, microcline, and limonite are common gangue minerals. A carbonatite dike is found in the area (M. H. Staatz, pers. commun., 1983).

Over a dozen thorium and uranium occurrences are found in the fluorite-copper-bastnaesite deposits in the Gallinas Mountains, Lincoln County (Fig. 37, Appendix 1). Although no uranium or thorium have been produced from this area; 71 tons (64 metric tons) of bastnaesite and 2,000 tons (1,814 metric tons) of fluorite, which assayed 6 oz/ton (187 grams/metric ton) silver, 22% lead, 6.93% copper, and 1.93% zinc, have been produced. Most of the production was from the Red Cloud and Rio Tinto claims (Griswold, 1959). The fluorite-copper-bastnaesite deposits occur as vein-fillings in breccia and fracture zones within the Permian Yeso Formation in the vicinity of syenite to monzonite laccoliths and sills. Up to 5% bastnaesite occurs in these deposits (Perhac, 1964; Perhac and Heinrich, 1964); however, less than 0.10% ThO_2 occurs in the bastnaesite. Although this area has been examined by Soulè (1946a), Rothrock and others (1946),

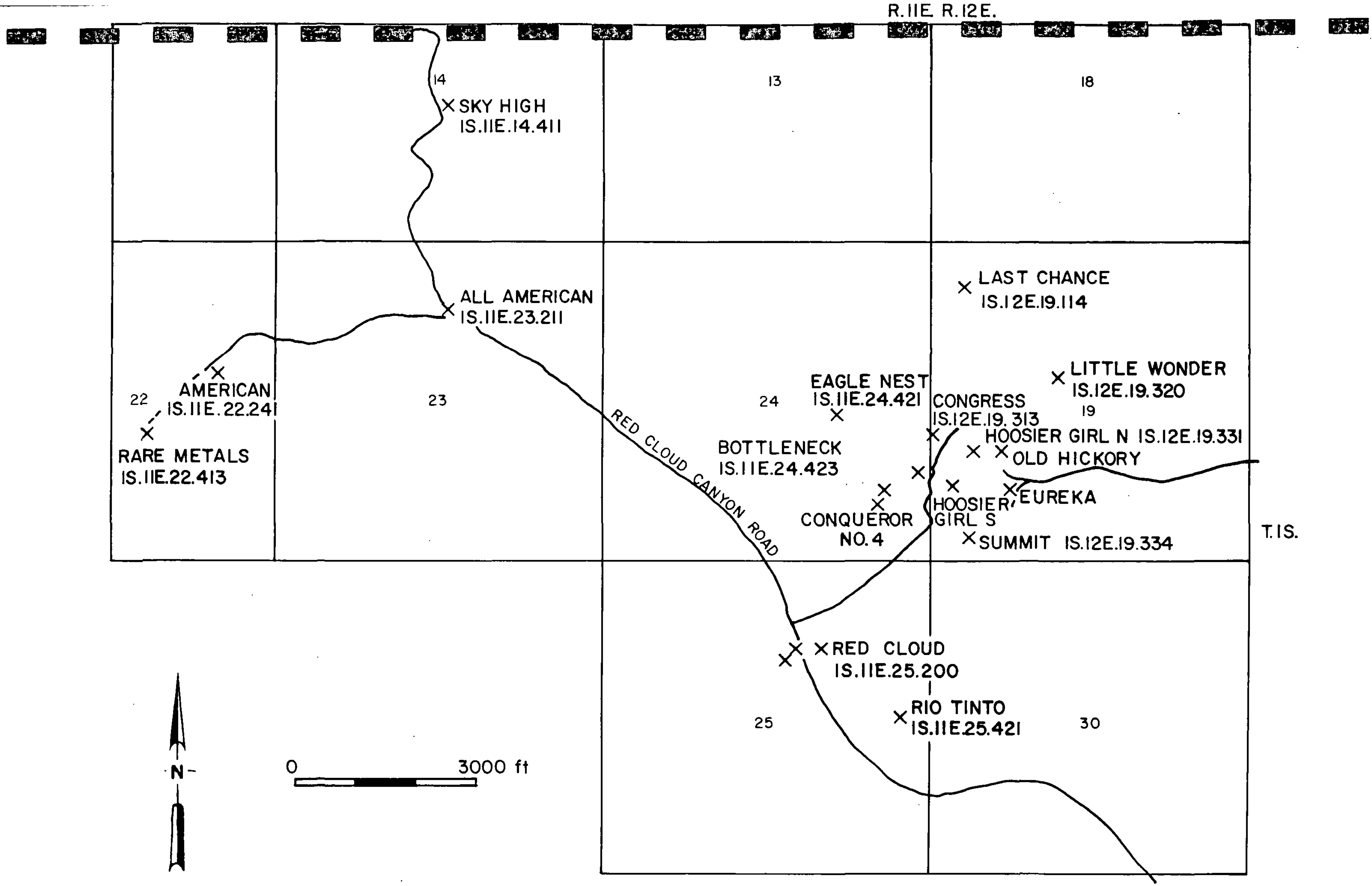
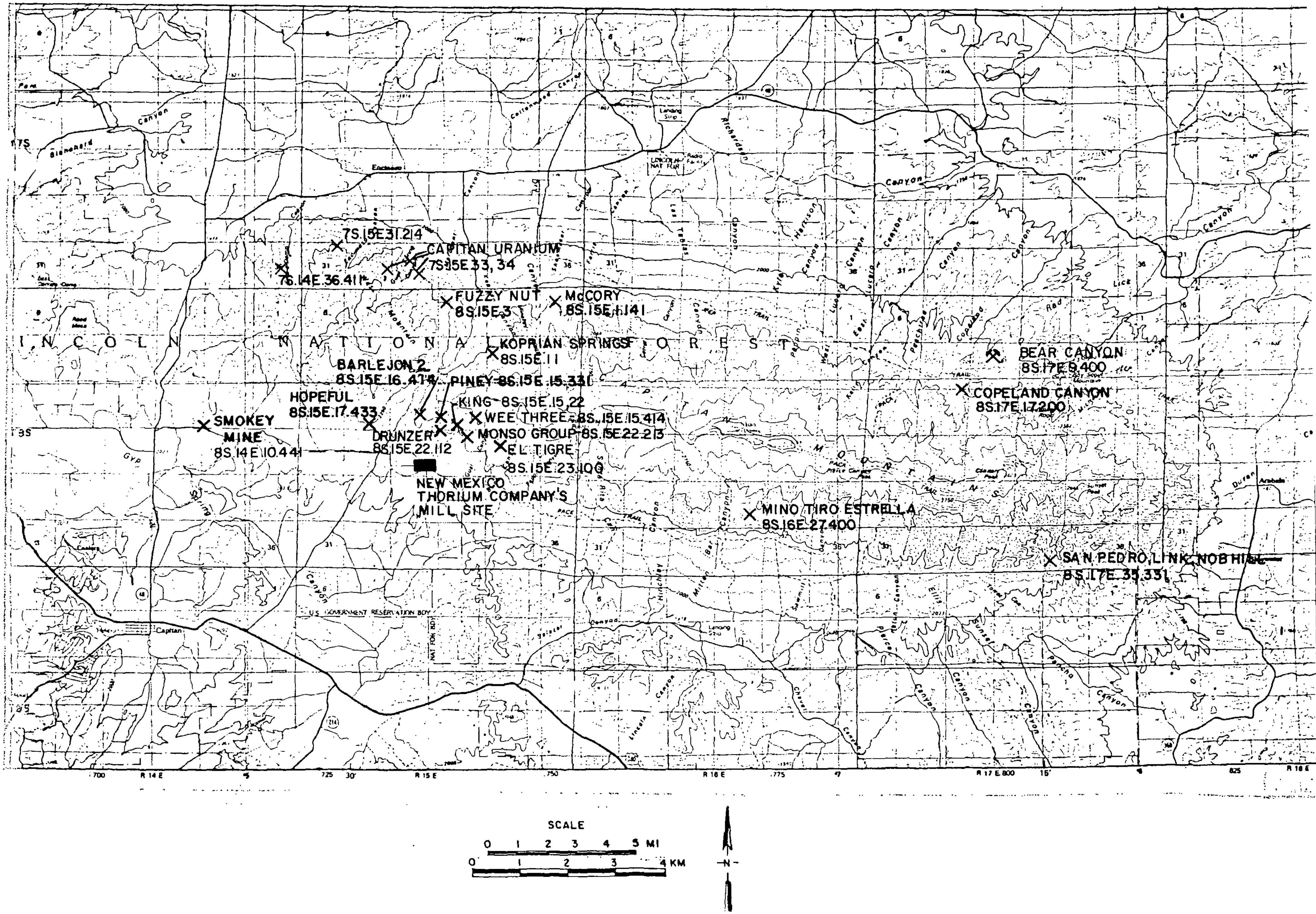


FIGURE 37–MINES AND PROSPECTS IN THE GALLINAS MOUNTAINS DISTRICT, LINCOLN COUNTY, NEW MEXICO. MODIFIED FROM ROTHROCK AND OTHERS (1946), GRISWOLD (1959), AND WILLIAMS (1966).

FIGURE 38—THORIUM VEINS IN THE CAPITAN MOUNTAINS, LINCOLN COUNTY, NEW MEXICO



Twenhofel and Brick (1956a, b), Griswold (1959), Perhac (1970), and Perhac and Heinrich (1964), additional studies are required to adequately assess any thorium or uranium potential.

During the 1950's, extensive exploration in the Capitan Mountains, Lincoln County, resulted in locating more than 69 anomalies found in 18 locations (Appendix 1, Fig. 38). Most of these anomalies contain dominantly thorium, however, some uranium is present (Appendix 1). The Mert Uranium Co. shipped 3 tons (3 metric tons) of "no pay" ore assaying 0.02% U_3O_8 from the Bear Canyon Group in 1954 (8S.17E.9.400, Appendix 1); this occurrence consists of a thorium-bearing iron deposit. A thorium mill was built by the New Mexico Thorium Company (Fig. 38) in the late 1950's, but it never processed any ore. The ruins of the mill have been dismantled by the U.S. Forest Service and only a small cleared area remains.

Thorium and uranium occurs as vein-fillings in high-angle shear and fracture zones in the intrusion that varies in composition from alaskite to monzonite and forms the Capitan Mountains. The continuity, size, shape, and strike of individual deposits are quite variable, and would restrict exploration and development. Some of the mineralized zones are up to 8 ft (2 m) wide and 1,000 ft (305 m) long. One sample from the McCory claims assayed 0.02% U_3O_8 and 217 ppm Th (Appendix 2). Additional thorium analyses reported by Staatz (1974) range as high as 1.12% Th. The major radioactive minerals are thorite and allanite (Griswold, 1959; Collins, 1956; Staatz, 1974), whereas, hematite and other iron oxides, fluorite, quartz, tourmaline, and feldspar are closely associated with the thorium veins. Rare-earth elements, molybdenum, copper, and gold occur with these deposits (Griswold, 1959; Collins, 1956). Dozer cuts, prospect pits, and a few adits are the only development of the veins (Appendix 1).

Thorium occurs in the syenite bodies in the Red Hills area of the Caballo Mountains, Sierra County. The syenite bodies have the character red to pink, irregular, dike-like zones within Precambrian granites and consist dominantly of microcline, with minor amounts of chlorite, hematite, biotite, apatite, anatase, barite, fluorite, bastnaesite, uranophane, and thorite. The contacts of these bodies are gradational except where cut by shear fractures. These features suggest a metasomatic origin, possibly a result of fenitization, although alkalic rocks and carbonatites are absent in the area (Staatz and others, 1965). Four occurrences of radioactive syenite bodies are described in Appendix 1; Staatz and others (1965) located more than 45 syenite bodies in less than a 2 mi^2 (5 square km^2) area. Samples contain up to 0.44% Th and 0.07% U_3O_8 (Staatz and others, 1965). Samples collected from the Red Rock No. 1 claim assayed 0.005% U_3O_8 and 104 ppm Th (Appendix 2). The potential for thorium and possibly uranium is fairly good in this area.

Thorium occurs in the Gold Hills and White Signal districts in the Burro Mountains, Grant County (Appendix 1). Thorite occurs along a basic dike intruding the Precambrian Burro Mountain granite at the Grandview Claims (Staatz, 1965; 1974). Up to 0.72% Th occurs in a two ft (0.6 m) long vein. In the White Signal district, thorium is noted in several localities

(Appendix 1). From 405 to 702 ppm are reported from Tullock Peak (O'Neille and Thiede, 1981), and from 547 ppm to 582 ppm Th from the Banner and Tunnel Site No. 1. Thorium content of 220 ppm occurs at the Blue Jay mine (O'Neille and Thiede, 1981). Thorium also occurs at the Purple Rock mine in the western portion of the Telegraph district. Other thorium occurrences in Grant County are in pegmatites and are described separately.

The Cornudas Mountains in Otero County are along the New Mexico-Texas border east of El Paso (Fig. 1). This area consists of nepheline-syenite laccoliths, sills, and dikes that have intruded Permian sediments (Zapp, 1941). These intrusive rocks form the northern extension of the Trans-Pecos magmatic province, and were emplaced about 35 m.y. ago (D. S. Barker, 1977; D. S. Barker, and Hodges, 1977; D. S. Barker, and others, 1977). Four localities of thorium and uranium mineralization occur within nepheline-syenite, eudiolyte-nepheline-syenite, and syenite dikes or sills (Appendix 1). Rare-earth elements, beryllium, niobium, nickel, columbium, lithium, tin, zirconium, and fluorite are associated with the thorium-rich alkalic rocks (Collins, 1958b; Holser, 1959a). Additional reconnaissance is required to adequately assess the thorium and uranium potential of this area.

Chemical analyses of samples from the El Porvenir district in San Miguel County and Tusas Mountains in Rio Arriba County are also anomalously high in Th (Appendix 1; Craig Goodnight, written commun., 4/24/82). Samples of hydrothermal veins from Gallina Creek area in the El Porvenir district contain up to 546 ppm eTh (radiometric equivalent Th; 17N.14E. 14.114, 17N.14E.14.144, Appendix 1). Samples of vein-type deposits from the Bromide No.

2 district in the Tusas Mountains contain up to 2% Th (Appendix 1, 28N.7E.13.333). These two localities may indicate additional areas containing thorium veins. Further geochemical sampling for thorium, niobium, and rare-earth elements is warranted in these areas.

Thorium and uranium deposits in Pegmatites

Pegmatites generally have potential for uranium and thorium, but are poor mining targets (Gableman, 1977, p. 89-90; J. W. Adams, and others, 1980). Uranium and thorium minerals are common in pegmatites, but are too scattered throughout the pegmatites to constitute an economic uranium or thorium deposit. Over 12,000 lbs (5,000 kg) of uranium have been produced from eleven pegmatites in the United States; about 10,000 lbs (4,500 kg) of this uranium production have come from the Platt pegmatite in Wyoming (J. W. Adams, and others, 1980, p. 2-3). Only two pegmatites in New Mexico have produced uranium; they are the Sparks Stone (15 tons = 14 metric tons ore that yielded 32 lbs = 14 kg U_3O_8) and the Pineapple #1 (4 tons = 4 metric tons ore that yielded 2 lbs = 0.9 kg U_3O_8) in San Miguel and Rio Arriba Counties (Table 7; Appendix 3). Uranium- and thorium-bearing minerals have been produced from at least eight pegmatites in San Miguel, Taos, and Rio Arriba Counties; however, their thorium and uranium contents are not known (Table 7).

At least 77 pegmatites in seven counties in New Mexico are radioactive and contain uranium- and thorium-bearing minerals (Appendix 1). Forty-nine radioactive pegmatites occur in Rio

Table 7 - Uranium and thorium production from pegmatites in New Mexico.
1- uranium and thorium content, in any, unknown
2- from U.S. Atomic Energy Commission production records, government contracts only, for the years 1948-1970 (Appendix 3).

Occurrence Number	Name	Production
	RIO ARRIBA COUNTY	
26N.8E.18.113	Fridlund	[1]5,000 pounds of columbite, samarskite, and monazite
26N.8E.36.221	Globe	[1]5,000 pounds of columbite
27N.8E.11.311	Kiawa, South Kiawa	[1]100 pounds of samarskite
27N.8E.36.332	Lonesome	[1]12 pounds of samarskite and monazite
26N.9E.30.233	Pineapple	[2]4 tons ore yielding 2 pounds U_3O_8 (0.03%)
26N.9E.18.133	Pino Verde	[1]few hundred pounds of monazite and bismutite
26N.8E.1.122	St. Joseph	[1]few pounds of mica, beryl, columbite-tantalite, and samarskite
	SAN MIGUEL	
18N.13E.36.400	Guy No. 1	[1]500 pounds of Ta-U-REE
16N.14E.5.132	Sparks Stone	[2]15 tons ore yielding 32 pounds U_3O_8 (0.11%)
	TAOS	
23N.11E.29	Harding Mine	[1]12,000 tons Ta-Li ore

Arriba County and 12 radioactive pegmatites occur in San Miguel County. In addition, radioactive pegmatites are found in Grant, Taos, Bernalillo, Hidalgo, and Mora Counties. Samarskite and monazite are the most common uranium- and thorium-bearing minerals found in New Mexico pegmatites, although other minerals, such as euxenite, crytolite, carnotite, uraninite, uranophane, fergusonite, thorite, allanite, hatchettolite, microlite, radioactive muscovite or biotite, and radioactive columbite, are locally found in these pegmatites. Selected uranium and thorium minerals are sporadically distributed in pegmatites and generally occur in pockets such as at Nambe (Fig. 39). Samples from these pegmatites collected by the author range as high as 0.13% U_3O_8 (Nambe, Rio Arriba County) and 10,332 ppm Th (Globe, Rio Arriba County; Appendix 2). However, it is doubtful that pegmatites in New Mexico will constitute a major source of uranium or thorum unless expensive hand-sorting mining methods are used.

Thorium and uranium deposits in Carbonatites

Carbonatites are carbonate-rich rocks of apparent magmatic derivation or descent, and commonly contain uranium and thorium minerals. Uranium has been produced from only one carbonatite complex in the world, the Palabora carbonatite complex in Transvaal, South Africa. Copper is the major commodity produced at Palabora; uranium and phosphate are by-products. Uranium reserves at Palabora are estimated as 10,000 tons (9,072 metric tons) of uranium at a grade of 0.004% (Nishimori and Powell, 1980). Several massive carbonatites in the United States are noted for their thorium content; thorium reserves from two of the

Figure 39 - Robert North is pointing to a pocket of monazite within the Nambe pegmatite, Rio Arriba County.

largest known deposits (Iron Hill, Colorado, and Sulphide Queen, California) are estimated as 40,830 tons (37,040 metric tons) (Staatz and others, 1982).

Only three areas in New Mexico are known to contain carbonatites; they are the Monte Largo Hills, Bernalillo County, and the Lemitar and Chupadera Mountains, Socorro County (Fig. 40). A small carbonatite dike has recently been discovered by M. H. Staatz (pers. commun., 1983) in the Chico Hills area, in Colfax County. These carbonatites occur as dikes, stockworks, and veins; large intrusive bodies such as at Palabora and Iron Hill, Colorado, have not been found in New Mexico. Alkalic rocks are absent from Lemitar and Chupadera Mountains in New Mexico, whereas at Monte Largo, Palabora, and Iron Hill alkalic rocks are associated with carbonatites. Alkalic rocks are associated with the Chico Hills carbonatite (M. H. Staatz, pers. commun., 1983).

Only two or three carbonatites dikes are present in the Monte Largo Hills, and a little over a dozen of them are in the Chupadera Mountains. Over 100 dikes and veins have been found in the Lemitar Mountains (McLemore, 1982b, 1983c). The Monte Largo and Chupadera carbonatites are not significantly radioactive, uranium concentrations are less than 0.005% U_3O_8 and thorium concentrations less than 119 ppm Th (Appendix 2). However, uranium concentrations as high as 0.25% U_3O_8 are found in the Lemitar carbonatites, whereas thorium concentrations are less than 74 ppm Th (McLemore, 1982b, 1983c). Pierson and others (1981) report that one carbonatite dike contains up to 1,950 ppm Th. The exposed dikes in all three of these areas indicate low-

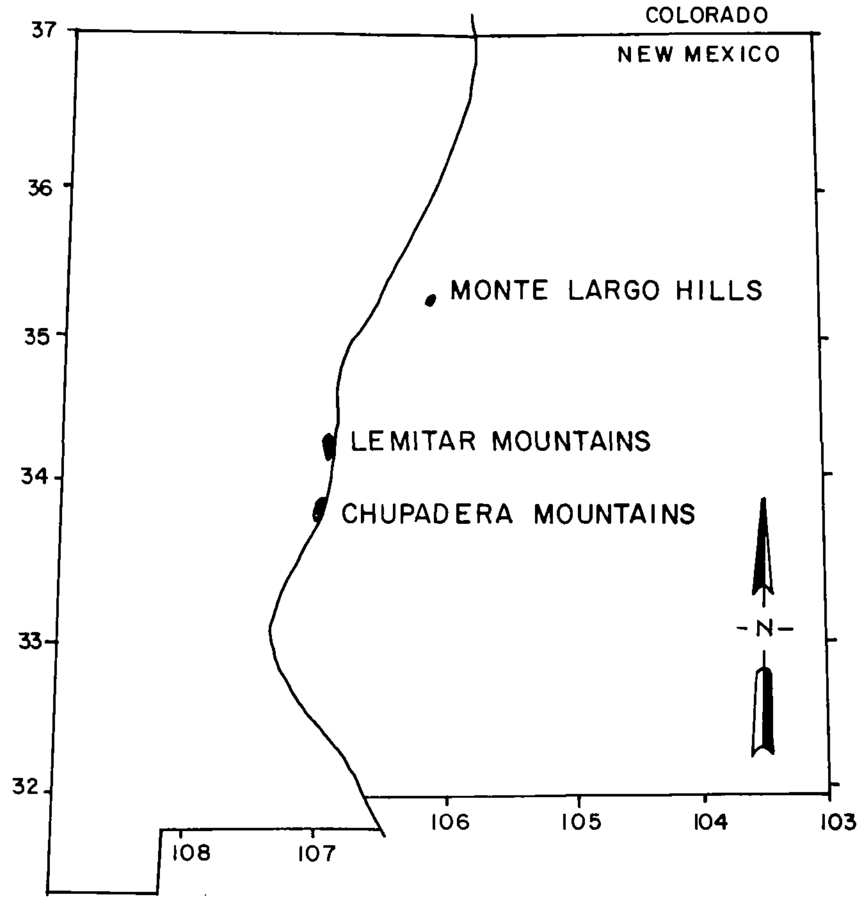


FIGURE 40–CARBONATITES IN NEW MEXICO

tonnages and low-grade uranium and thorium deposits. However, high-grade and large tonnage deposits may exist at depth. Any uranium or thorium would probably be produced only as a by-product of another commodity such as titanium, niobium, or rare-earth elements.

Deposits in Volcanic Rocks

Numerous uranium occurrences are related to volcanic rocks throughout north-central and south-central New Mexico (Appendix 1; McLemore, 1982a); however, only one volcanogenic deposit, the Terry (Pitchblende Strike) in Sierra County, has yielded ore. In 1955 and 1960, 127 tons (115 metric tons) of ore yielding 359 lbs (163 kg) of U_3O_8 at an average grade of 0.14% was produced (Appendix 3). Uranium mineralization at the Terry deposit occurs in an andesite sill along ring fractures of the Nogal Canyon cauldron. The presence of high concentrations of fluorite associated with the uranium mineralization hampered milling of this ore (Irving Rapaport, pers. commun., 1983).

Minor uranium occurrences are found in volcanic rocks and along ring fractures and cauldron margins throughout southwestern New Mexico (Appendix 1). Many of these are associated with corresponding water and stream-sediment anomalies (McLemore, 1982a). Only the Nogal Canyon cauldron appears to have any uranium potential (U.S. Department of Energy, 1980), but many of these areas have not been adequately examined for uranium potential.

Deposits of Uncertain Origin

Vein-type deposits in sedimentary rocks

Vein-type deposits in sedimentary rocks are controlled by structure. The source of the uranium, mode of transport, and depositional mechanisms are unknown. In New Mexico, vein-type deposits occur in breccia pipes (discussed separately) and along the Rio Grande Valley in Socorro and Sierra Counties (Appendix 1). Uranium mineralization occurs along faults and fractures in sandstones and limestones. High-grade, but small-tonnage, deposits are common.

One of the largest vein-type deposits is the Jeter mine in the Ladron Mountains, Socorro County (McLemore, 1983b; Hilpert, 1969; Chamberlin and others, 1982). From 1954 to 1958, 58,562 lbs (26,563 kg) U_3O_8 at an average grade of 0.33% were produced from the Jeter mine.

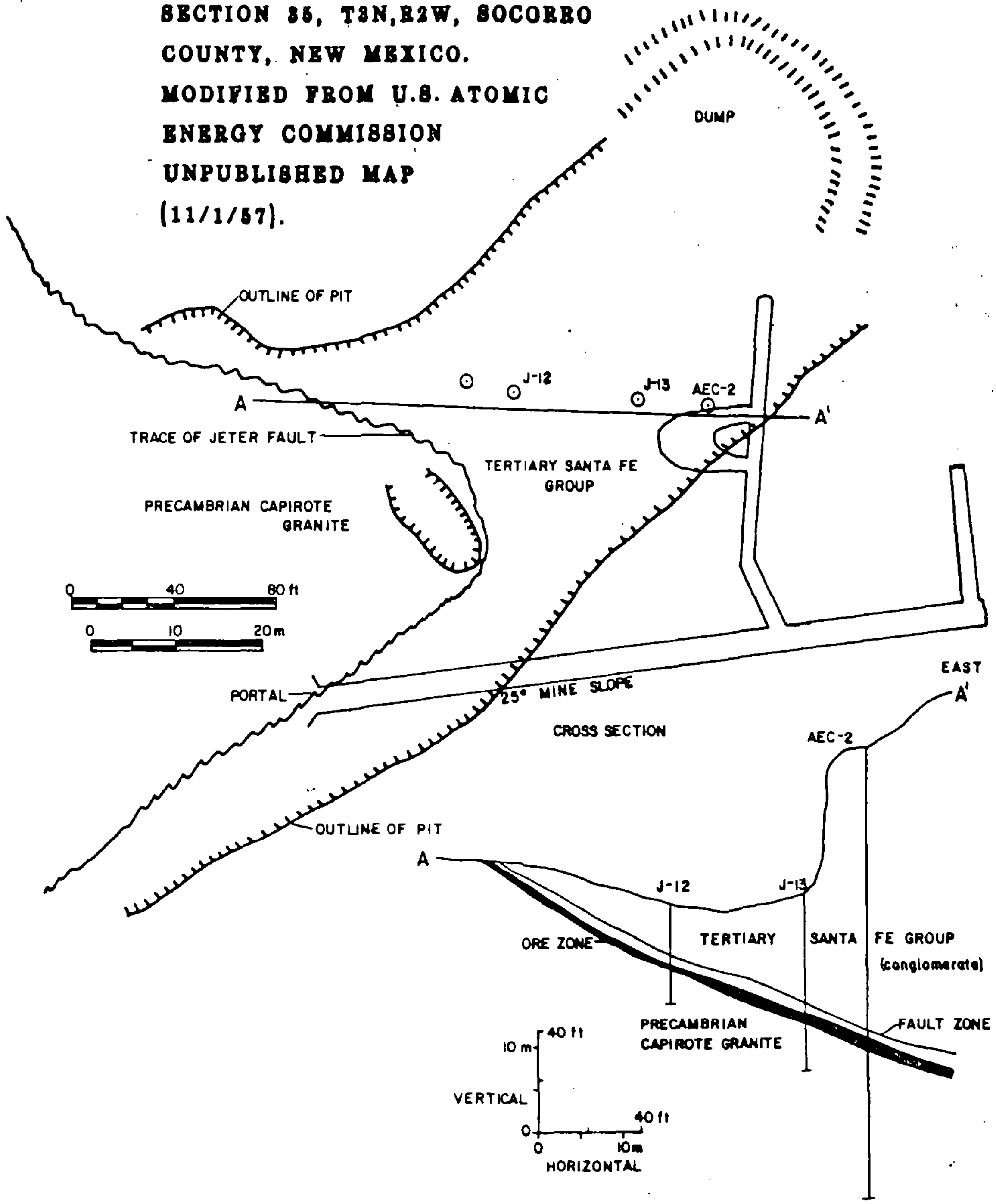
Uranium and copper minerals occur within a carbonaceous mudstone that forms a fault breccia along the footwall of a fault separating the Precambrian granite from the Quaternary-Tertiary Santa Fe Group (Chamberlin and others, 1982; Hilpert, 1969; Collins and Nye, 1957). The primary uranium mineral is coffinite (common to many sandstone deposits), which appears to be confined to the fault breccia (Collins and Nye, 1957a). Two ore bodies were mined by an open-pit and a 300-ft 25° decline (Fig. 41). At least seven additional copper occurrences, some of which are associated with uranium are situated along the major fault zone (Chamberlin and others, 1982; Appendix 1).

The origin of the Jeter deposit is controversial. It has been described as being hydrothermal (Collins and Nye, 1957; U.S. Department of Energy, 1980) and as a vein-type deposit (Hilpert, 1969; Pierson and others, 1980). However, the Jeter deposit lacks the symmetrical alteration, mineralogy, and silicification characteristic of hydrothermal and vein-type deposits (Chamberlin and others, 1982). A supergene (Chamberlin and others, 1982) or hypogene (B. A. Black, 1964) origin is suggested on the basis of kaolinization, bleaching, lack of silicification, and mineralogy. In trace element analyses of vertically oriented samples at the Jeter mine (Pierson and others, 1981), uranium and vanadium decrease from top to bottom, whereas molybdenum is concentrated in the middle. This geochemical signature, typical of Wyoming-type sandstone deposits, is interpreted by Chamberlin and others (1982) to represent a supergene origin. Additional chemical analyses of vertically oriented samples and samples updip and downdip of the Jeter deposit are needed to verify this geochemical signature. For the purposes of this report, the Jeter deposit is classified as a vein-type deposit of unknown origin.

Numerous vein-type uranium occurrences are present along the Rio Grande Valley in Socorro and Sierra Counties (Appendix 1). Production from five of these occurrences amounts to 4,688 lbs (2,126 kg) of U_3O_8 (Appendix 3). The Lucky Don-Little Davie mines produced 4,229 lbs (1,913 kg) of U_3O_8 alone. Other producing mines include Aqua Torres, Maria #1, and Paran claim (Appendix 3).

Most of the vein-type occurrences are in partly silicified

FIGURE 41-PLAN MAP OF THE JETER MINE, SECTION 35, T3N,R2W, SOCORRO COUNTY, NEW MEXICO. MODIFIED FROM U.S. ATOMIC ENERGY COMMISSION UNPUBLISHED MAP (11/1/57).



and recrystallized limestones and sandstones along the footwall of major fault systems. Uranium mineralization is sporatic and discontinuous along these faults. Secondary yellow uranium minerals are common.

At the Agua Torres and Maria #1 mines, north-trending faults separate the Permian Abo Formation from the mineralized Pennsylvanian Madera Limestone. Ore shipments as high as Ø.23% U_3O_8 are reported from these deposits (U.S. Atomic Energy Commission, ore production reports, 1955-1956).

Uranium mineralization at the Lucky Dog and Little Davie mines occurs in silicified and recrystallized limestones of the Permian San Andres Limestone. A northeast-trending fault controls uranium mineralization and separates the Permian Yeso Formation and San Andres Limestone. Selected samples from the Lucky Dog and Little Davie mines assayed Ø.38% and 1.4% U_3O_8 (Appendix 2).

Uranium mineralization occurs along the east-west-trending Garfield fault system in the southern end of the Caballo Mountains in Sierra County, at the Paran, Hot Rock, and Treasure Uranium claims (Appendix 1). Mineralization is sporadic and discontinuous, and only the Paran claims have yielded any ore (Appendix 3).

Small vein-type uranium occurrences may be found along faults elsewhere in the Rio Grande valley. One such occurrence is in the Cretaceous-Tertiary McRae Formation in the Fra Cristobal Mountains. Most of these occurrences are minor and less than Ø.Ø1% U_3O_8 (Appendix 1).

The origin of these deposits is speculative. It is possible that vein-type uranium deposits in the Rio Grande valley may be related to sandstone deposits. Similar processes could deposit uranium in both sandstones and along faults. Hydrothermal solutions may also have formed these deposits. Further work is needed to define and classify these vein-type occurrences.

Breccia-pipe deposits

Brecia-pipe deposits are vertical or steeply dipping cylindrical features bonded by ring-fractures and filled with a heterogenous mixture of brecciated wall rocks. Over 600 breccia-pipes are found in the Ambrosia and Laguna subdistricts, but only a few are mineralized (Hilpert, 1969; Nash, 1968; Moench, 1962). Pipe structures in the Cliffside (D. S. Clark, and Havenstrite, 1963), Doris Decline (Granger and Santos, 1963), and Jackpile-Paguate mines (Hilpert and Moench, 1960) have yielded ore as part of the sandstone deposits; the exact tonnage attributed to these breccia-pipes is not known. Very little brecciation has occurred at the Cliffside and Doris pipes, however, these pipes appear to be related to other breccia pipes in the area. The Woodrow deposit is the largest uranium producer from a breccia-pipe in New Mexico (Appendix 3).

Breccia-pipe deposits in New Mexico range from 5 to 200 ft (1.5 to 61 m) in diameter and up to 300 ft (91 m) or more in length (Megrue and Kerr, 1965). The Woodrow deposit is about 24 to 34 ft (7 to 11 m) in diameter and at least 300 ft (91 m) long. In Arizona, the mineralized Orphan Lode breccia-pipe is 150 to 500 ft (45 to 152 m) in diameter and at least 1,500 ft (457 m) long (Gornitz and Kerr, 1970). Additional mineralized breccia-pipes occur in Arizona, where production has exceeded 4 million lbs (1.8 million kg) of U_3O_8 at an average grade of 0.43% (Scarborouh, 1980, 1981). Over 134,000 lbs (61,000 kg) of U_3O_8 at an average grade of 1.26% U_3O_8 was produced from the Woodrow deposit in New Mexico (Appendix 3).

Breccia-pipes in Arizona occur in Permian rocks, whereas similar deposits in New Mexico occcur in Jurassic rocks. Uranium-lead dating of the uranium in the Orphan Lode deposit in Arizona implies deposition before Late Jurassic, 140 million years ago (Gornitz and Kerr, 1970; Berglof, 1969), whereas dating of uranium in the Woodrow deposit suggests mineralization at 90-100 million years ago (Berglof, 1969; Nash, 1968). Similarities in form, structure, alteration, and mineralogy between the Orphan Lode and Woodrow deposits may indicate a similar origin despite their differences in size and age. The origin of these breccia-pipe deposits is controversial. Solution collapse of underlying strata, such as limestone or evaporites, could have formed these pipes (Hilpert and Moench, 1960; Gornitz and Kerr, 1970; Scarborough, 1981). Mineralizing fluids entered the permeable collapse feature and deposition of uranium and copper minerals occurred.

It is possible that additional breccia-pipes remain undiscovered in the Grants uranium district; but whether they will be of sufficient grade and tonnage for economic deposits is uncertain. Numerous small but high-grade breccia-pipe deposits have been found recently in Arizona (Scarborough, 1980; Nash,

1983) but the potential for similar deposits in New Mexico appears to be unfavorable (Green and others, 1980b, c).

Numerous clastic plugs and dikes, similar to breccia-pipes in the San Juan Basin, occur throughout the Cimmarron valley area in Union County. The origin of these plugs may be due to solution collapse, faulting, or filling from below the plug (B. H. Parker, 1933; Consulting Professionals, Inc., 1980). Copper mineralization is commonly associated with these plugs, but only one or two plugs contain uranium mineralization (Appendix 1; Consulting Professionals, Inc., 1980). The Ft. Pitt Copper Co. plug (Appendix 1) contains up to 0.004% U_3O_8 (W. I. Finch, 1972). Consulting Professionals, Inc. (1980) located a mineralized plug in the Bentz Arroyo south of Goodson School, which contains 32 ppm U_3O_8 and 0.3% Cu; however, they were unable to locate any additional uranium mineralization in these plugs.

Deposits in diatremes

A diatreme is a funnel-shaped volcanic rock or pipe which formed by a violent eruption into the enclosing sediments. Over 300 diatremes occur in the Hopi Buttes volcanic field in New Mexico and Arizona; most of these diatremes are in Arizona. Two petrographic types are found. Monchiquite diatremes are common in the southwestern part of the volcanic field in Arizona, whereas limburgite or minettes are found in the northeast portion in Arizona and New Mexico (Shoemaker, 1956a; Green and others, 1980b). Only one diatreme has produced uranium; 192 tons (174 metric tons) of ore averaging 0.15% U_3O_8 was produced from the Seth-la-kai diatreme in Arizona (Lowell, 1956; Chenoweth and

Malan, 1973). None of the diatremes in New Mexico have been exploited for their uranium content.

The minettes are highly potassic basaltic rocks with anomalous amounts of Ba, Sr, Be, B, U, and rare-earth elements. Uranium and thorium analyses from the Outlet Neck, Bennett Peak, and Mitten Rock in New Mexico range from 10.6 to 12.3 ppm U and from 28.4 to 50.1 ppm Th (Shoemaker, 1956a, p. 183). Only two diatremes in New Mexico are known to contain uranium minerals. The Shiprock diatreme contains 0.082% U, and the East Side (or King Tutt) diatreme is also impregnated with uranium minerals (Appendix 1).

In Arizona, where the balk or mineralized diatremes occur, uranium is associated with the bedded limestone or travertine deposits that formed within maars. The maars are a direct result of the collapse of the diatreme; lake sediments formed within the maars (Chenoweth and Malan, 1973; Scarborough, 1981; Green and others, 1980b). The diatremes of the ancient Hopi Lake in Arizona are considered a favorable area for potential uranium deposits (Green and others, 1980b). The uranium occurrences in diatremes in New Mexico do not exhibit any favorable characteristics similar to the Arizona diatremes, and their uranium potential then must be regarded as poor.

Unconformity-type deposit

Some of the world's largest high-grade uranium deposits are found in unconformity-related deposits in Canada and Australia (Mickle and Mathews, 1978). Unconformity-related deposits are vein-like deposits that occur at a Precambrian unconformity between crystalline basement rocks and overlying Precambrian sedimentary rocks. However, Langford (1980) suggests that all unconformities below continental deposits of Precambrian to Cretaceous times should have uranium potential. For the purposes of this report only Precambrian unconformity-related deposits are considered.

The Sangre de Cristo Mountains in northern New Mexico exhibit the greatest similarity to the unconformity-related model (Kalliokoski and others, 1978). An unconformity separates marine phyllites of the Ortega Group from the amphibolites and fluvial sandstones and conglomerates of the Vadito Group. The stratigraphic relationships between the Ortega and Vadito Groups are uncertain; it is currently believed that the Ortega Group is the older unit (Nielson and Scott, 1979). The U.S. Geological Survey and others (1980) describe an unconformity that separates a quartzite from a younger stratified sequence near Rio Mora, in the Pecos Wilderness and adjacent areas. Anomalous water and stream-sediment samples high in uranium occur in the general vicinity of these areas (Morgan and Broxton, 1978; Boliver, 1980).

F. B. Barker (1958) and Bingler (1968) did not recognize any unconformities in the Precambrian terrane in the Tusas Mountains in Rio Arriba County. However, Gresens (1976) describes an unconformity that separates the younger Ortega Group (metasedimentary rocks) from an older basement of metavolcanic and metasedimentary rocks. T. R. Gibson (1981) and Kent (1980) have mapped a part of this unconformity. It is not known whether uranium occurrences in the area are related to the unconformity.

Additional unconformities may exist in the Precambrian terrane in New Mexico which may be favorable for uranium exploration (McLemore, 1982a). Other unconformities in southern New Mexico and in the Rio Grande valley area have been recognized but appear to be unfavorable for uranium mineralization (McLemore, 1982a). At the present time, none of the New Mexico uranium deposits appear to be representative of the unconformity-related model, although the potential for locating such deposits may exist.

Uranium and Thorium Potential Resources and Reserves in New Mexico

Uranium resources are defined by the U.S. Department of Energy (DOE, 1980) as the sum of known uranium reserves and estimated potential uranium resources. Reserves are known quantites of uranium ore that have been measured directly. Potential resoruces are the quantities of undiscovered uranium ore believed or expected to occur in areas of known production or in areas of favorable geologic settings or formations. Potential resources are divided into probable, possible, or speculative (Fig. 42).

Reserves and potential reserves are divided into selected maximum forward-cost categories ($30, $50, and $100 per pound of U_3O_8) to cover current economic conditions. Cost categories do not represent the price at which uranium would be sold because expenditures prior to reserve calculations are not included. Forward-cost categories only include capital and operating costs which have not yet been incurred. The price necessary to support a 15% rate of return would be 1.3 to 1.5 times the forward cost per pound of U_3O_8 (U.S. Department of Energy, 1980, p. 136).

Uranium reserves are compiled yearly by the DOE and released in "Statistical data of the uranium industry". Uranium resources in New Mexico have been discussed by Hilpert (1969), McLemore (1981), Chenoweth (1982), and Harris and Carrigan (1981). All of the uranium reserves and the majority of the potential resources in New Mexico are in the San Juan Basin area (Tables 8 and 9, Fig. 43). About 112,500 tons (102,058 metric tons) of $30 per pound of U_3O_8 reserves are in the San Juan Basin, New Mexico

Table 8 - Uranium reserves for ore reserve areas in the San Juan Basin as of January 1, 1983. Information supplied by the Minerals Assessment Division, Grand Junction Area Office, U.S. Department of Energy. See figure 43 for location of resource areas. [1] Includes \$30 reserves.

Resource Area	\$30/lb U_3O_8 Reserves Short Tons U_3O_8	\$50/lb U_3O_8 Reserves [1] Short Tons U_3O_8
Ambrosia, Mt. Taylor and East Chaco Canyon	51,000	115,000
Laguna, Chama Basin, and Nacimiento	4,000	40,000
Blackjack, Gallup, West Chaco Canyon, and Shiprock	18,000	46,000
Total	73,000	201,000

Table 9 - Potential uranium resources for resource areas in New Mexico as of January 1, 1983. Information supplied by the Minerals Assessment Division, Grand Junction Area Office, U.S. Department of Energy. See Figure 43 for location of resource areas. [1] Includes $30 resources.

Resource Area	$30/lb U_3O_8 Category Short Tons U_3O_8 Probable	Possible	$50/lb U_3O_8 Category[1] Short Tons U_3O_8 Probable	Possible
COLORADO PLATEAU (1/1/83)				
Shiprock and West Chaco Canyon	27,667	22,146	60,750	53,622
Gallup	10,410	2,198	22,072	5,374
Blackjack	14,437	473	31,578	2,179
East Chaco Canyon	3,315	12,469	7,351	28,519
Ambrosia	17,212	5,644	35,113	12,602
Mt. Taylor	26,237	4,356	54,779	10,149
Laguna	7,874	1,802	15,361	4,269
Nacimiento and Chama Basin	2,327	4,117	4,540	8,938
Central Basin	-	6,922	-	19,867
Subtotal	109,479	60,127	231,544	145,519
BASIN AND RANGE (1/1/83)				
La Bajada-Hagan	844	-	2,801	-
Subtotal	844	-	2,801	-
TOTAL	110,323	60,127	234,345	145,519

Figure 42-Definition of Resourse Classes

RESERVES	+	POTENTIAL RESOURCES	=	URANIUM RESOURCES
(Defined by direct sampling)		(Incompletely defined or undiscovered)		
		PROBABLE POSSIBLE SPECULATIVE		

(Table 8), about 55% of the total $30 reserves in the United States (DOE, written comm., 1981). About 109,479 tons (99,318 metric tons) of $30 per pound of U_3O_8 probable resources are in the San Juan Basin, New Mexico, and about 884 tons (766 metric tons) of $30 per pound of U_3O_8 probable resources are in the La Bajada-Hogan basin area (Table 9, Fig. 43). The total of $30 probable resources in New Mexico is about 110,323 tons (100,083 metric tons).

Most of New Mexico's potential uranium reserves are in sandstone deposits of the Jurassic Morrison Formation in the Colorado Plateau. Uraniferous limestones and sandstones of the Jurassic Todilto Limestone and Cretaceous Dakota Formation also occur in this area (McLemore, 1981b; U.S. Department of Energy, 1980). Additional areas outside the San Juan Basin are also highly favorable for containing uranium deposits, although only minor production, if any, is reported from many of these areas (McLemore, 1981b, 1983a). Most of these areas have been discussed in this report and by McLemore (1981b). Upon the increase in demand for uranium, exploration in these areas may resume.

Thorium reserves and resources in New Mexico have not been adequately evaluated and are little known. This is due in part to the lack of an economic demand for thorium and the apparent low grade and low tonnage of thorium deposits in New Mexico. An estimate of thorium reserves in all known beach-placer sandstones in the San Juan Basin was made as part of a titanium and iron resources study by Dow and Batty (1961); who estimated that collectively 4,751,200 tons (4,310,200 metric tons) of ore containing less than 0.10% $eThO_2$ (radiometric equivalent ThO_2) occurs in these deposits. The reliability of this estimate is uncertain.

The largest thorium reserves in the United States are in vein-type deposits (Staatz and others, 1979). Thorium veins in New Mexico are known to occur in Colfax, Lincoln, Sierra, Grant, Rio Arriba, and Otero Counties, and would constitute most of New Mexico's thorium resources. Additional minor thorium occurrences in New Mexico may be found in pegmatites in the Tusas and Sangre de Cristo Mountains and in carbonatites in Socorro County, but the presently available data suggest that thorium is sporadic and low-grade in these areas. Most of these areas have been described in this report. Thorium reserves in New Mexico probably are insignificant when compared to other areas in the United States (Staatz and others, 1979), and will probably remain unknown unless an economic demand for thorium is established.

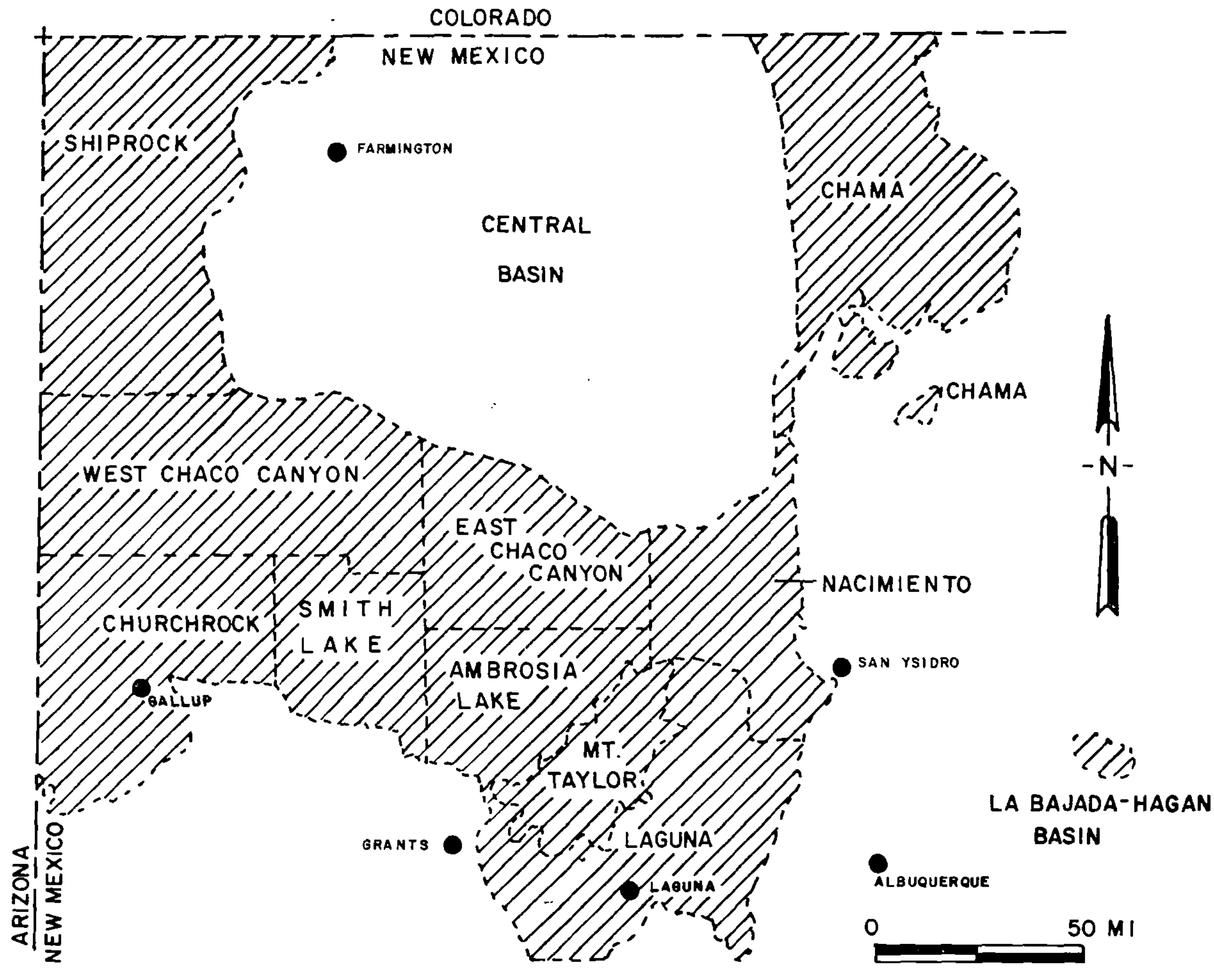


FIGURE 43-POTENTIAL RESOURCE AREAS IN SAN JUAN BASIN

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